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BMC REPAIRED CENTURY OLD WATER PIPELINE

THE PIPE

Tansa main pipeline | Brings water from Tansa dam to island city

100 km | Length

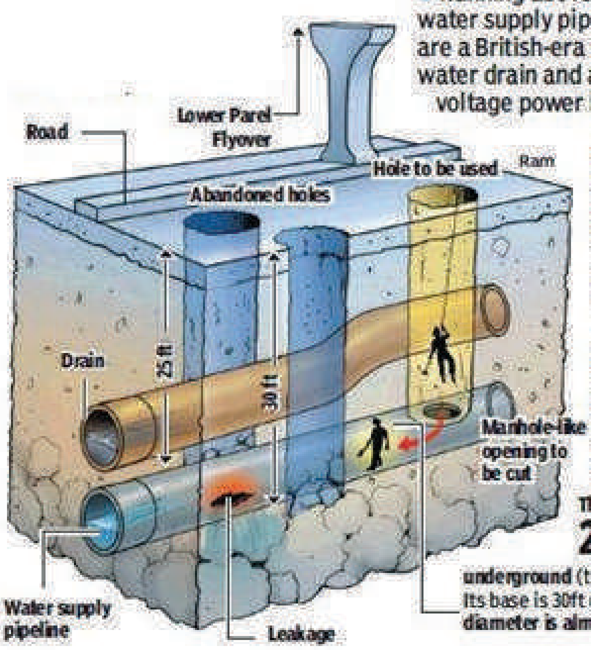
145 cm | Diameter. A **5ft-tall person** can stand inside the pipe

Damage | The pipe has been leaking for over a month. Exact spot **was detected with an ultra-sound rod**

THE CHALLENGE

- Running above the water supply pipeline are a British-era storm water drain and a high voltage power line
- So, the pipeline cannot be accessed by direct overhead digging
- To reach it, BMC engineers had to bore a hole at a distance

100 years
Age of pipeline
Laid during British rule



The pipe is **25ft** underground (top surface). Its base is 30ft under, since its diameter is almost 5ft

The plan is to drill a manhole-size circle on the pipe, enter it, and then reach the leakage spot from the inside

2 other holes were bored, but had to be abandoned as rocks made further ingress difficult

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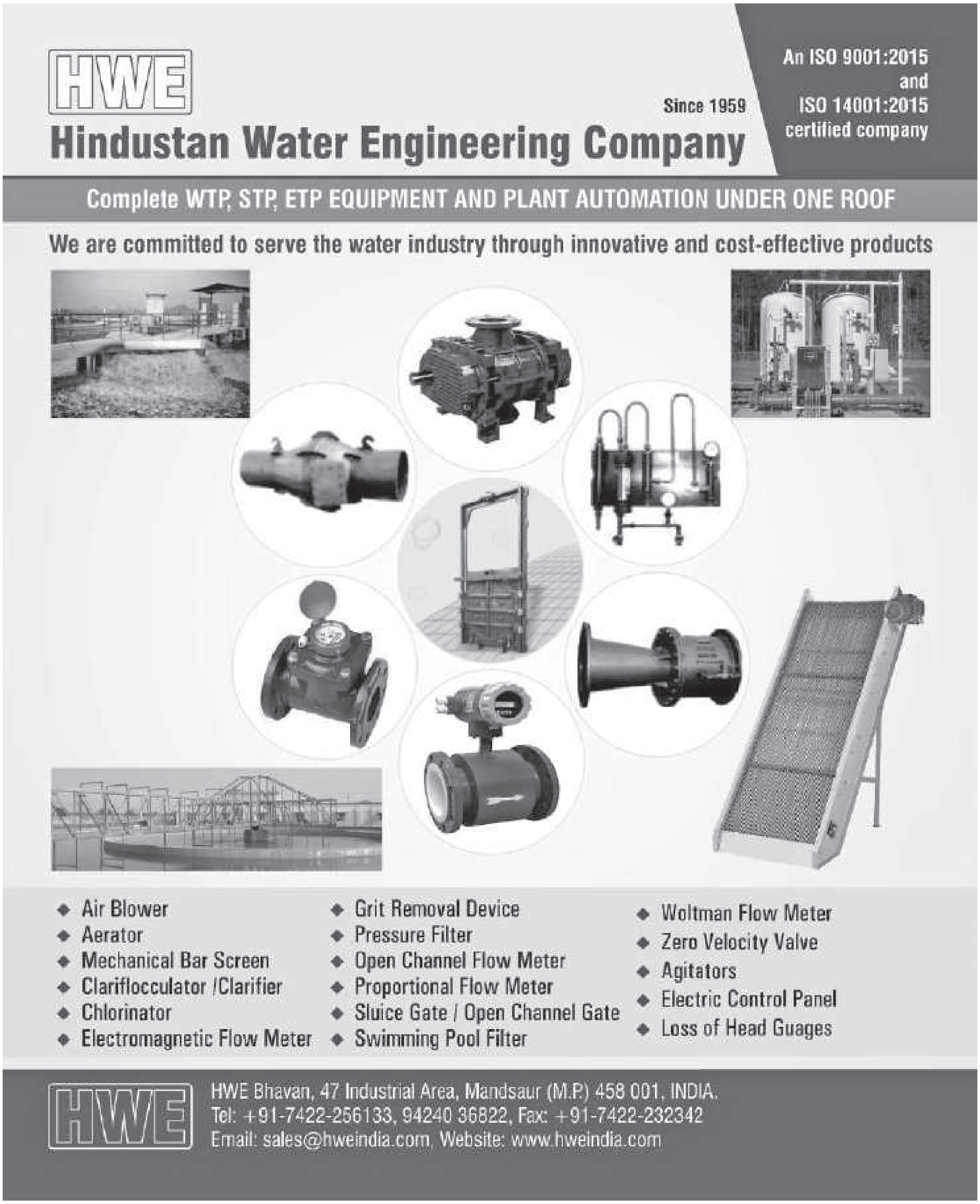
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FROM THE EDITOR'S DESK

I feel happy and proud to be appointed as the Editor of the Journal of Indian Water Works Association (JIWWA). I am honoured and pleased to serve as the Editor of the JIWWA. I am aware of the responsibilities that the Editor role entails. I approach my new role with both excitement and some trepidation! Becoming the editor of a journal dedicated to the Water, which is 'Amrut' meaning 'Ambrosia', a God sent opportunity. I sincerely promise that I will strive my best without sparing any pains to maintain the standards, my predecessors have established. Firstly, thanks to IWWA for choosing me as the Editor and secondly my thanks are due to my predecessor Shri Magan Lal Agarwal. Over the past 4 years he has done a fantastic job, shaping the journal to ensure that it has maintained its place as the leading Water Journal of India. He has acted always with the utmost professional integrity with prodigious appetite for hard work combined with his deep understanding of water issues in India, makes him a hard act to follow. On this occasion, I express my gratitude to Bangalore Water Supply and Sewerage Board where I served for straight thirty-seven years, for giving me the wide recognition as a Water Professional. Apparently, this has resulted in me becoming the Editor of our IWWA journal.

Drinking water, in adequate quantity and quality, is a basic requirement for life and a determinant of standard of living. These days, about drinking water, though there is lot of awareness and currently not being taken for granted, but continues to be carelessly contaminated and regularly wasted. 'Drinking Water' covers a huge host of topics: the history and distribution of water, politics, debates, economics, the environmental impact and water preservation efforts. The Water Industry is set to embrace several changes in the coming years due to rapid urbanisation, grave climate changes, soaring customer expectations, and emerging digital technologies including the future water technology trends. These trends are set to bring innovative use cases to transform the water industry and ensure the sustainable management of water and its availability. All these could be properly documented. For all these, JIWWA is the best platform for dissemination.

The subjects mentioned above pose a complex set of challenges should be worth addressing in JIWWA. I request Authors to develop their articles on these fields, on which they have hands-on knowledge and working experience. IWWA journal is soliciting case study manuscripts in water management field for articles that may be included after Peer review. Seasoned experts involved in Water Sector shall contribute their experience in the form of articles, illustrations, case studies etc. I also request Authors to share more on their practical experience on prototype solutions. Our Young engineers who are looking for a way to enhance their professional profile, JIWWA is their good platform. Sharing knowledge by publishing an article is an invaluable addition to their curriculum vitae. The editorial board of the journal includes international experts on various aspects of Water Management and has a primary goal of reviewing submitted papers and deciding on publication status within three months. All papers will be blind reviewed and accepted papers will be published by JIWWA which will be available online and in printed version. I hope that the publication can enrich the readers' experience by exposure to recent developments in the water field that they might otherwise miss. In general, this JIWWA, functions as a channel for the learned to contribute their ideas in Water and Energy involved in Water Sector to the learning and also to the other functionaries of the Government and Private sectors. Eligible contributions would catch the eyes of the Government or Private sector in our country or abroad for further practical implementation.

Under my editorship, I sincerely hope, Journal of IWWA publishes papers reviewed, original research papers on all aspects of the science, technology and management of water and wastewater and its management in an unbiased manner. Hence, I request all the Experts and budding youngsters to make use of this platform in a fitting manner to contribute to the benefit of water utilities and professional colleagues. Given the secure footing of the journal I do not propose any immediate or radical changes under my leadership, however JIWWA will need to continue to evolve to ensure full advantage is taken of the rapidly changing world of publication and digital information dissemination. I am already working on this, and to make JIWWA fully digital compliant to the extent possible. I am fortunate to be supported by a highly effective team; the current group of review committee who will work incredibly hard particularly in the assessment and processing of submitted articles. As we move forward together, I request with all humility for cooperation from IWWA members and welcome their ideas, recommendations, and substantive research contributions. I look forward to engaging the crucial issues in water management that lie before us all.

(Dr. P. N. Ravindra)
Hon. Editor Journal

Hydraulic Modelling of Distribution Network of 24x7 Water Supply Using Variable Frequency Drive Pump

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Abstract: *Recently Central Public Health and Environmental Engineering Organisation (CPHEEO) modified its design norm (Addendum, 2023) of residual nodal pressure. It is now recommended to be in the range of 15-21 m at critical node of the distribution network. However, in India, many service reservoirs have staging height less than 12m and may not be able to meet the pressure requirement by any change in pipe sizes. Hence, the Guidelines for 24x7 water supply recommended direct feeding of networks and recommends use of Variable Frequency Drive (VFD) pumps adopting smart control philosophy instead of constant speed pumps. A new network can be easily designed with VFD pump installed at clear water sump of Water Treatment Plant (WTP) to pump water directly into the distribution network. However, for an existing network with less staging height of service reservoirs, installation of VFD pump at outlet of such service tank is desirable to increase the residual nodal pressures to 15 to 21 m, Say 18 m. This paper aims at preparing the GIS based hydraulic model of direct feeding of networks for 24x7 water supply by adopting VFD pumps. Further, one operational zone of the Ayodhya city (including famous Ram Mandir), comprising of two DMAs is (prepared using the WaterGEMS software) is considered for illustration. Various alternatives using constant speed as well as VFD pumps are compared with the objective to maintain a residual head of 18 m head at the critical point throughout the day.*

Key Words: *24x7 water supply project, Distribution Network, GlS, variable frequency drive pump, WaterGEMS.*

1. INTRODUCTION

In India, water distribution networks (WDNs) are usually designed to achieve a residual head of 7 to 12 m for supply to single and double storied buildings respectively. Considering the supply of drinkable water from consumer taps without the requirement of storage and household treatment as far as possible, the recent guidelines from CPHEEO recommend a residual pressure of 15 to 21 m at all nodes throughout the day. A combined pumping and gravity network are preferrable by constructing a service reservoir which provides sufficient storage to take care of fluctuating demand and allow the pumps to operate at constant head. In this case, pumps are selected to have their duty point in the best operating zone (most efficient zone) and service reservoir incidentally acts as a break-pressure tank, allowing the network on downstream of the reservoir to work as gravity-fed network. However, with the increase in residual head requirement, a combined pumping and gravity network may not be feasible in some cases due to restriction on the height of reservoir. Further, maintaining higher residual pressure in an existing network with the existing service reservoir may not be possible. In such cases, a direct feeding to distribution network through pumps is desirable. As the demand and pressure requirements in the network are varying throughout the day.

a constant speed pumps should not be used as it may not operate in best efficient zone for most of the time in a day. Variable frequency drive (VFD) pumps are suitable for feeding distribution networks directly, and hence recommended by CPHEEO. VFD pumps can work at different speeds allowing the pumps to operate more efficiently in different period of varying demand and pressures.

As direct feeding distribution networks using VFD pumps have many advantages like, energy saving and assured 24x7 continuous supply with required residual pressures at critical points, it is recommended to adopt this method in metro cities where the distribution network of proper pipe materials is available, and electricity is continuously available through express feeders.

This paper aims at describing the hydraulic principle of VFD pump and show its application on improvement of an existing network to achieve desired pressure throughout the day.

A comparison of complete gravity (or combined pumping and gravity feed) and direct feed networks is shown in Table 1.

Table 1: Comparison of gravity feed and direct feed networks

Sr. No.	Gravity Feed Network	Direct Feed Network
1	The distribution network is connected to elevated service reservoir (ESR) or hill service reservoir.	The distribution network is connected directly to pump water into the distribution pipelines. Each pump group may feed 2-4 District Meter Areas (DMA).
2	Variation in network demand is covered by buffer storage volume in the service reservoir.	Variation in network demand is controlled through pump speed/output.
3	Level based, fixed speed of pumps	Demand based, pressure control at variable speed of pumps by defining system head to meet required pressure at critical points.
4	High variation in residual pressure at critical point (highest elevation) in the network.	Residual pressure in network at critical point is maintained in narrow band.
5	Comparatively high energy consumption	Most energy efficient operation.

2. PRINCIPLE OF VFD PUMP

A Variable Frequency Drive (VFD) is a motor controller (https://instrumentationtools.com) that drives an electric motor by varying the frequency and voltage supplied to the electric motor. The frequency can be changed using electronic drive circuit which then alters the rotational speed of pump. Frequency (or hertz) is directly related to the motor's speed denoted by the Revolutions Per Minute (RPMs). In other words, the higher the frequency, the faster the RPM of the pump

When VFD pump starts, AC wave is generated. Frequency of the AC wave is defined as the number of cycles of signal that took place in a second. Frequency is measured in Hertz (Hz). For example, if 50 complete cycles are produced in 1 second, then the frequency of the given wave is 50 Hz. In India, the value of frequency is 50Hz. This value is standardized and widely used around the world as the standard frequency for the alternating current (AC). Relation between the rotation, frequency and the number of poles is given by,

$$N = RPM = \frac{120f}{P} \quad \text{(Eq. 1)}$$

Where: N=Rotation/minute (RPM); P= Number of poles; and *f*=Supply frequency.

2.1 Pump Head-Discharge Curve

The pump curve denotes the relationship between rate of fluid flow and head for the pump itself. Flow is on x-axis and the pressure head generated by pump is shown on the Y-axis as in Fig.1. Starting point of the pump curve is at the point of zero flow, at which the pressure head generated by the pump is called as *shutoff head*. It descends and the lowest point is at maximum flow rate. Even though a pump can operate over a long range of discharge and head, its efficiency will not be same at different points. Best operating zone is defined as the zone over which pump efficiency is more than some desirable efficiency. A pump is selected to operate in best operating zone.

2.2 Effect of VFD on Pump Performance:

The curves indicating stable pump operation range as recommended by the manufacturer shall be used. It is an envelope formed by (Q_{min} - Q_{max}) conditions at minimum and maximum speed. Q_{min} is the minimum flow (LPS or LPM or m^3/hr) at minimum rated speed N_{min} (in RPM), and Q_{max} = maximum flow (LPS or LPM or m^3/hr) at maximum rated speed N_{max} (in RPM).

Affinity Laws: Affinity laws are used to calculate head or power consumption in centrifugal pumps when changing speed or wheel diameters. Thus, for the same impeller diameter, when the pump speed changes, flow rate is directly proportional to the speed, so also the head is directly proportional to the square of the speed. If a pump delivers a discharge Q_1 at a head H_1 when running at speed N_1, the corresponding values when the same pump is running at speed N_2 are given by the similarity (affinity) laws:

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \quad \text{(Eq. 2)}$$

$$\frac{H_2}{H_1} = \left(\frac{N_2}{N_1}\right)^2 \quad \text{(Eq. 3)}$$

$$\frac{P_{i2}}{P_{i1}} = \left(\frac{N_2}{N_1}\right)^3 \text{ (Eq. 4)}$$

Where, Q = discharge (m^3/s, or l/s), H = pump head (m), N = pump rotational speed (rpm) and P_i = power input (HP, or kW).

2.3 The System Head Curve

The system head curve represents relationship between head and flow of the distribution pipe network. It shows how much head is required to push flow rate through the pump and into the distribution system. As the head loss in pipe network increases with increase in flow, the system head curve shows increase in head due to increase in water flow through the pipework. The total head, H that the pump delivers includes the elevation head and the head losses incurred in the system. The friction loss and other minor losses in the pipeline depend on the velocity of the water in the pipe, and hence the total head loss can be related to the discharge rate.

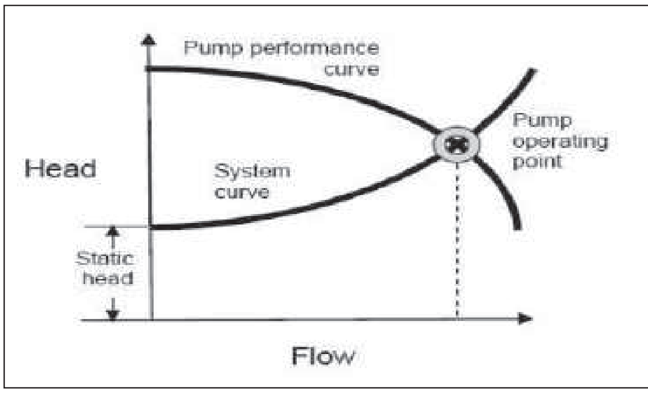

Fig. 1: *Operating point of pump*

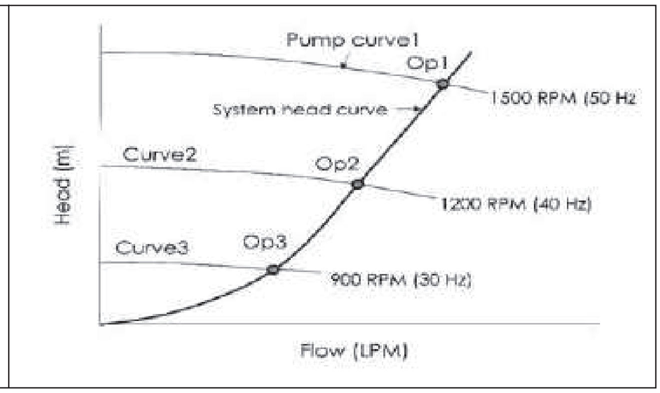

Fig. 2: *Attainting operating points on system curve*

System Head for a simple pumping main can be defined in mathematical form as:-

$H_s + (R * Q^n)$ (Eq. 5)

Where, H_s denotes static lift, i.e difference of elevation head at critical point in the pipeline and lowest suction level; and R is resistance of pipe in the head loss equation. Value of n can be 1.852 or 2.

2.4 Selection of Pump

A proper pump is selected by considering both the System Curve and the Pump Curve. When combined, pump curve intersects the system head curve (Figure 1) which is called as the *operating point*.

2.5 System Head Curve for Complex Network

System head curves can be easily developed for a system with tanks on both the suction and discharge side of the pump as discussed and shown abve in Fig/ 1, which is termed as an *open system* (Walski et al. 2010). But most of the distribution system do not have tank (floating tank) on the downstream side of the pump, which is called as a *closed system*. Usual methods of creating system head do not work on such (closed) systems. In such situation hydraulic model is used to create system head curve.

For a given pump group, there can be several system curves for a particular network. However, a unique system head-capacity (H-Q) curve can be plotted by analysing residual pressure requirements at critical point in the network. Figure 2 shows a system head curve and three pump curves for different rotational speeds of single pump system with four number of poles. There is one VFD for this pump.

In Fig. 2, pump curve 1 is for frequency of 50 Hz with operating point Op1 for maximum demand say in peak hour. When the demand reduces, the frequency is lowered to say 40 Hz and the operation point shifts to Op2. At mid night the demand is least and the pump speed is further reduces say 30 Hz. And the operating point shifts to Op3. In this way the change in demand is dealt with alteration in the rotational speed of the pump.

3. HYDRAULIC MODELLING WITH VARIOUS OPTIONS

One operational zone (Hanuman Garhi) of Ayodhya city is shown in Fig. 3 and its network is shown in Fig. 4. DMA1 is shown in green colour and DMA2 in blue colour. The existing network consists of 234 nodes and 278 pipes. The network is fed from an elevated service reservoir of 12 m staging, which is found insufficient to meet the residual pressure requirement of 18 m at some of the nodes. The most critical node in the network is J-1.

Different options for improving network performance are considered. Hydraulic modelling is carried out for obtaining performance: (1) during period of maximum demand (peak hour) using steady state; and (2) for the entire day using extended period simulation (EPS). Available heads at the critical nodes are compared for different options.

3.1 Modelling in Steady State with Constant Speed Pumps

Option 1. In this option, it is assumed that existing service reservoir is discarded. A direct pumping to distribution network through constant speed pump is considered from the sump (Fig. 5). The supply level in the sump is taken as 100 m.

Fig. 3: *Network with DMAs*

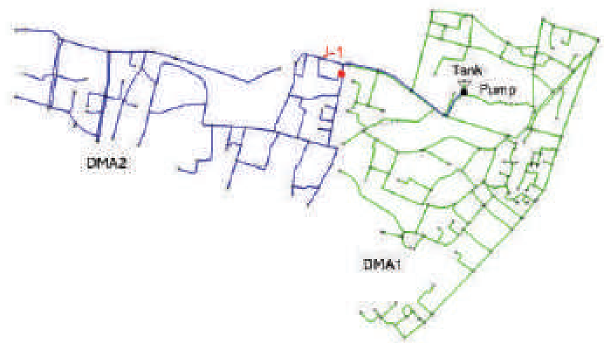

Fig. 4: *Network of one operational zone of Ayodhya*

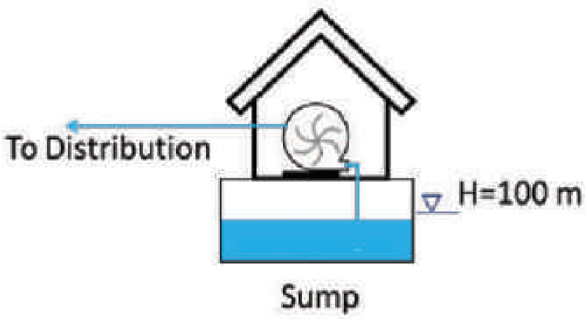

Fig. 5: *Scenario 1: Direct pumping from the sump*

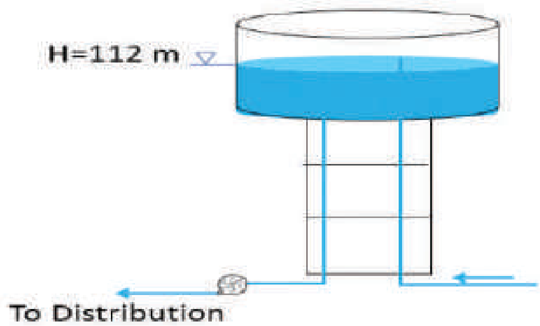

Fig. 6: *Scenario 2: Boosting by installing pump on the outlet of the tank*

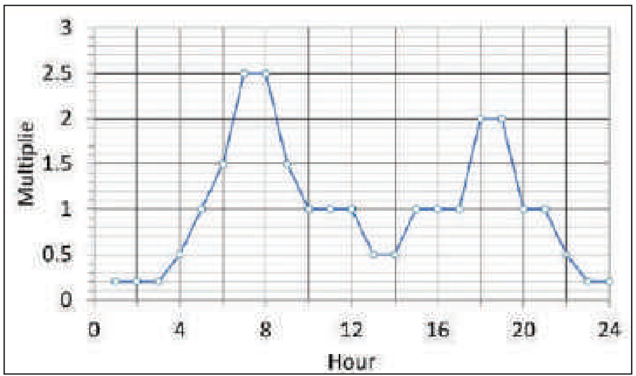

Fig. 7: *Peak factor*

Option 2. Reservoir is retained and an online boosting is provided by installing pump on the outlet of the tank (Figure 6). As mentioned earlier, reservoir height is 12 m, and the same is taken as supply level in steady state analysis.

The required head for the pump to meet the residual pressure requirement of 18 m at junction J-1 is obtained using steady-state model for peak hour demands using WaterGEMS software. The minimum required head at pump is observed to be 26.6 m for the design flow of 8.788 MLD for the option-1. In the option 2, the design head of booster pump is observed to be reduced to 14.6 m due to positive suction head of 12 m provided by the service reservoir. Obviously, the option-2 is better than option-1. Thus, it can be concluded that the existing ESRs even with less staging height cannot be the hurdle and can be very much utilised when the retrofitting exercise is taken up to increase the residual nodal pressures to 18m. For a flow of 8.788 MLD and 14.6m head, we need just 25.7 HP pump and cost of electricity (at Rs 8/kwH) would be Rs 3,678 per day.

3.2 EPS with Constant Speed Pump

The model with network as shown in Fig. 4 is changed to the Extended Period Simulation (EPS) by assigning the pattern of multiplier factors (Fig. 7) to each of the nodes. EPS run is obtained for both the options. The available pressure at some of the nodes including the critical node J-1 are shown at 0 Hr and starting of the peak hour (7 Hr) are shown for the two options in Figs. 8 and 9, respectively. Further, available pressures at these nodes observed during steady-state analysis are shown side by side for comparison. The following can be observed from Figs. 8 and 9:

- In both the options, pressures in steady state are more or less equal to the pressures in EPS at 7 hours (peak hours) as steady state analysis was carried out for 7h demand scenario. Small difference could be due to change in water level in the reservoir in the two options.
- EPS provides available pressure more than 18 m during 0-Hr at all the nodes. A comparison of the EPS results for both the options are shown in Fig. 10. Although not shown in the Fig. 10, the availability of higher residual heads can be observed during all non-peak hours.

As the values of available pressures at the critical node J-1 at 0-Hr and other non-peak hours are more than 18 m, it indicates over consumption of energy. Usually, in the field, in such a situation, the operating point of pump shifts and may go out from best operating zone resulting in working of pump at lower efficiency and thus incur higher energy costs. Hence, VFD pumps are better option to maintain 18m at the critical node J-1 at all the time

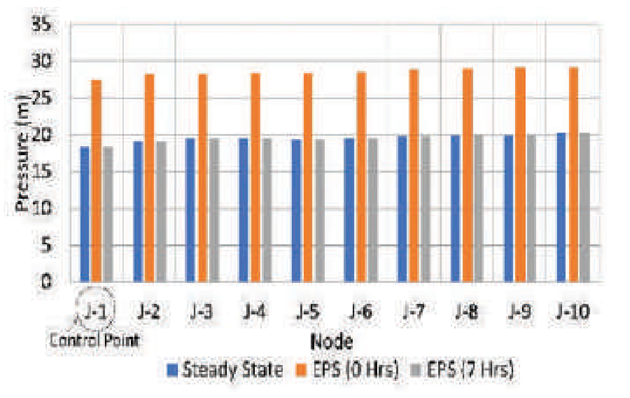

Fig. 8: *Option 1: Direct pumping from sump Steady State*

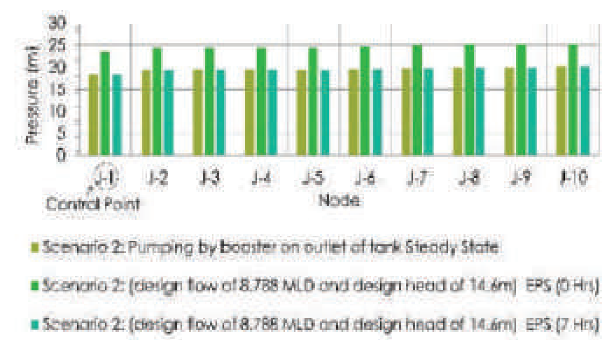

Fig. 9*: Option 2: Pumping by booster on outlet of tank.*

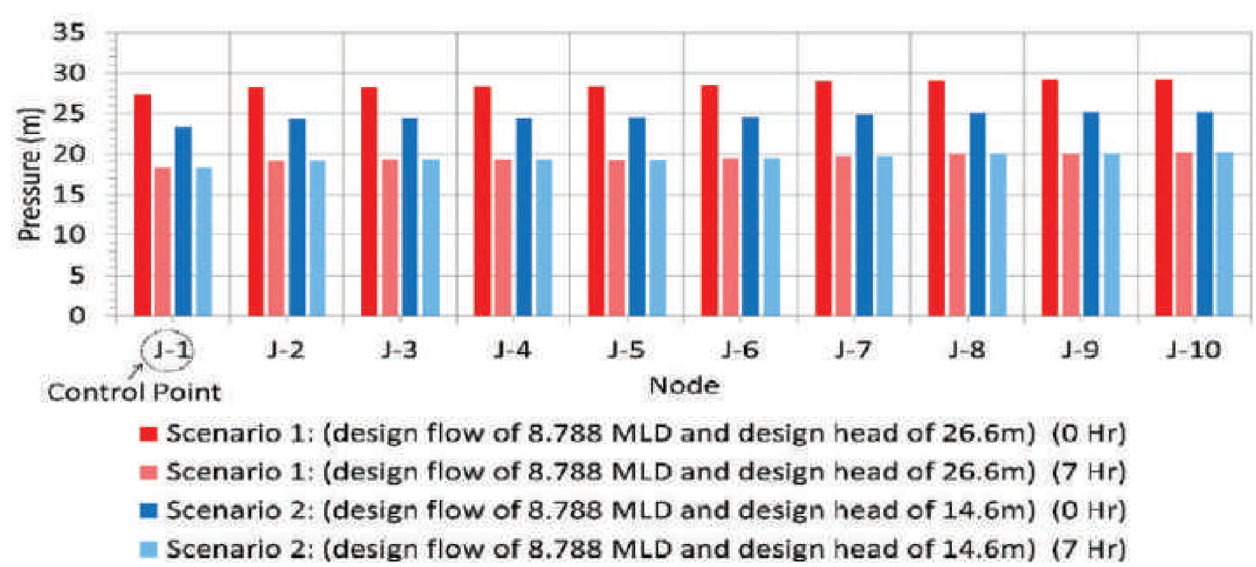

Fig. 10: *EPS results of pressure at nodes*

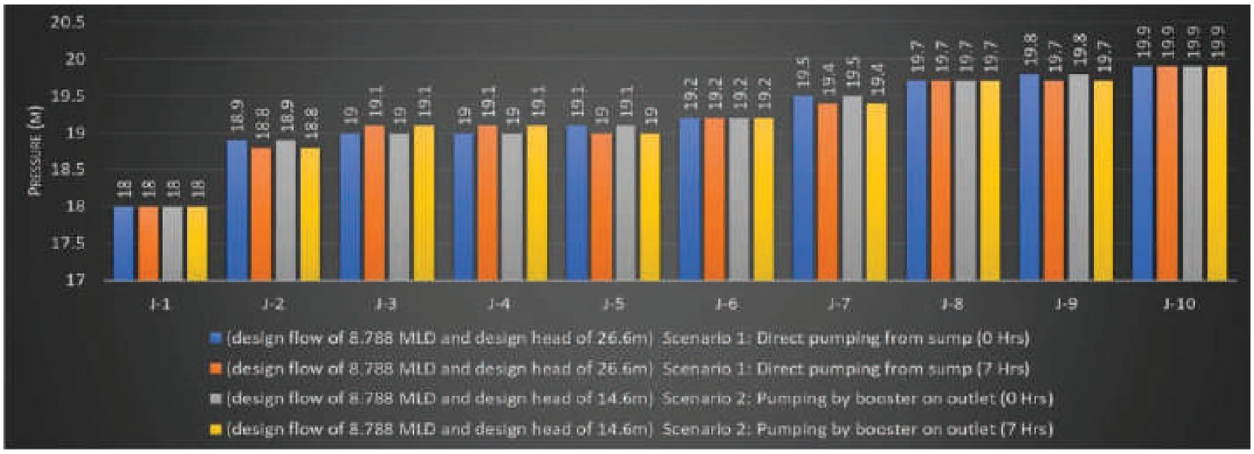

Fig.11: *Pressure at nodes*

3.3 EPS Model using VFD Operated Pump

3.3.1 Principle Utilised in the Software

Relative Speed Factor: In the network software, the parameter, "*Relative Speed Factor*" is used to compute the speed of pump. It is defined (Mădulărea, et al 2019) as ratio between the actual pump speed and its maximum speed. If the value of relative speed factor of the pump is calculated by the software as 0.7, it means the speed calculated is 70% of the full speed (where full speed means the pump characteristic curve as has been entered in the pump definition).

The relative speed factor (https://communities.bentley.com) is determined by how much head and the corresponding flow it takes to maintain the fixed head. It will be adjusted accordingly to maintain the pressure at the critical node. The software calculates the values of relative speed factor of the pump for all the heads and flows for different points of time in a day. Thus, if the values of relative speed factor are known, the RPM of the pump can be known and by feeding them to the actuator, the actual pump speed can be adjusted.

Hence, the objective of the running the model is to compute the Relative Speed Factors at different point of times in a day which are required to maintain the 18m head at the critical node.

Table 2: Relative Speed Factors of the VFD pump

Time (hours)	Scenario 1: Direct pumping from the sump (Design Flow of 8.788 MLD and Design Head of 26.6m)	Scenario 2: Boosting by installing pump on the outlet of the tank (Design Flow of 8.788 MLD and Design Head of 14.6m)
0	0.858	0.716
1	0.858	0.716
2	0.858	0.716
3	0.858	0.716
4	0.863	0.722
5	0.88	0.743
6	0.909	0.777
7	0.995	0.877
8	0.995	0.877
9	0.909	0.777
10	0.88	0.743
11	0.88	0.743
12	0.88	0.743
13	0.863	0.722
14	0.863	0.722
15	0.88	0.743
16	0.88	0.743
17	0.88	0.743
18	0.948	0.822
19	0.948	0.822
20	0.88	0.743
21	0.88	0.743
22	0.863	0.722
23	0.858	0.716
24	0.858	0.716

3.3.2 Running Model with VFD Pump

Option 1: (Direct pumping from the sump): The value of the relative speed factor of the VFD pump is set as 1. With elevation of 100m in the tank, the model is run in EPS with the VFD operated pump. The model results of few nodes are shown in Fig. 11.

Option 2: (Boosting by installing pump on the outlet of the tank): With elevation of 112m in the tank, the model is run in EPS with the VFD operated pump. The model is run for the same value of the relative speed factor of 1 and the model is run. Results of the few nodes are shown in Figure 12.

From Fig. 11, it can be observed that the values of residual pressure (m) at the critical node (J-1) are now exactly equal to 18m in both Scenarios 1 and 2 for 0 and 7 hours. In fact, the same is observed at other non-peak hours also. This is due to reduction in motor RPM. The relative speed factors of the pump at various time are shown in Table 2.

Thus, VFD controller adjusts the RPM of motor as per the requirement. Depending upon the requirement VFD controlled pump can be designed. Obviously, VFD pumps are costly as compared to constant speed pumps. However, they results in lowing of energy consumption and prove to be economical in long run.

5. CONCLUSIONS

The main advantage of 24x7 supply is that there is no chance of contamination from outside as the pipelines are always pressurised. Further, it is necessary that water is available to consumer at its tap. Considering the same, the CPHEEO in recent guidelines increased the residual pressure requirement at the service point of consumer to 15-21 m. maintaining high residual pressure may require need of direct pumping either using constant speed pumps or variable flow drive pumps.

The network of the operational zone (Hanuman Garhi) of the Ayodhya city has been modelled in the WaterGEMS software using both types of pumps. For maintaining the 18m at critical node, the software computed the values of the relative speed factors of the VFD operated pump. After knowing the relative speed factors of the VFD operated pump, the pump curves from the manufactures' Catalog can be selected. In this way a single pump with same impeller can deal with change in demand in non-peak and peak hours. In case, if variation in minimum and maximum discharge through VFD pump is large, a floating reservoir at suitable locations on downstream of network can be tried to reduce the difference between maximum and minimum flow through VFD.

Smart pump control philosophy can be implemented to regulate the pumps operation at variable speed meeting varying demand throughout the day as well as maintaining required minimum residual pressure at critical point in the distribution network. This also reduces energy consumption and pressure fluctuations in the system.

It is recommended to adopt this method in metro cities where the distribution network of proper pipe materials is available, and electricity is continuously available through express feeders.

6. REFERENCES

Addendum, (2023). Retrieved from https:// mohua.gov.in/ publication.php? sa= manuals-and-advisories.php

https://communities.bentley.com

Madularea R.A., Georgescu P.O. and Georgescu, S.C. (2019). "Speed factors computed for pumping schedules in Water Distribution Networks: DDA versus PDA formulations," *E3S Web of Conferences* 85, 06002 (2019)

EENVIRO (2018). Retrieved from https://www.e3s-conferences.org/articles.

Walski et al. (2010). "Developing System Head Curves for Closed System," *Journal AWWA*, September 2010

Indigenous Water Management Practices: Suranka System in Kasargod, Kerala

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Abstract: *Life without water cannot be thought about. Water distinguishes the life of every living creature, which is very limited, and its availability is very limited. Fresh water is required to meet domestic economic development and environmental needs, and there will be regions that cannot meet these needs day to-day life. While looking into the aspects of Kerala, it's rich in matters of water resources, even though it can't meet the needs of the people during the summer season. The water resources are rich during the rainy season, and they would be scarce during the dry season. When water is treated as a scarce resource, the system of water conservation of Suranga becomes much more popular due to not only its water discharging technique but also its water recharging strategy. It is created in the soil itself, with no other harmful objects or strategies used. The study used a case study approach to access the details of the system and tries to document the details collected from the field. The system can solve the issues pertaining to water scarcity to a certain extent.*

Key Words: *Indegenous Water Management Practices, Surankas, Water Recharging, Water Conservation, Water Policy, Water Governance, Surface Water, Ground Water*

1. INTRODUCTION

Water is a very essential resource for every living organism. Without such a vital resource, life cannot be sustained on the earth. The availability of freshwater resources, only 3% is fresh and one third is locked up in the glaciers. Water is getting more and more scarce, and there is currently very little fresh water available.

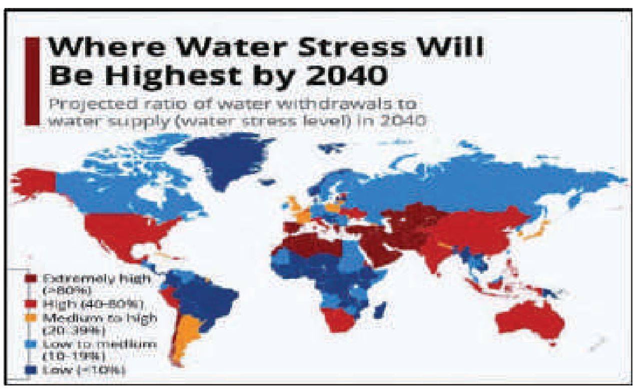


Fig. 1: *Source: World Resources Institute via The Economist Intelligence Unit*

Water-related issues have become widespread in the modern era, necessitating the use of the phrase "Water Governance" to handle the problem's various levels of complexity. In addition to meeting home, commercial, and industrial needs, it ensures clean and safe drinking water. And to meet all the demands for water, environmental sustainability must be maintained. To achieve poverty reduction, inclusive growth, food security, public health, sanitization, a dignified life, and environmental harmony, it is crucial to have access to clean water.

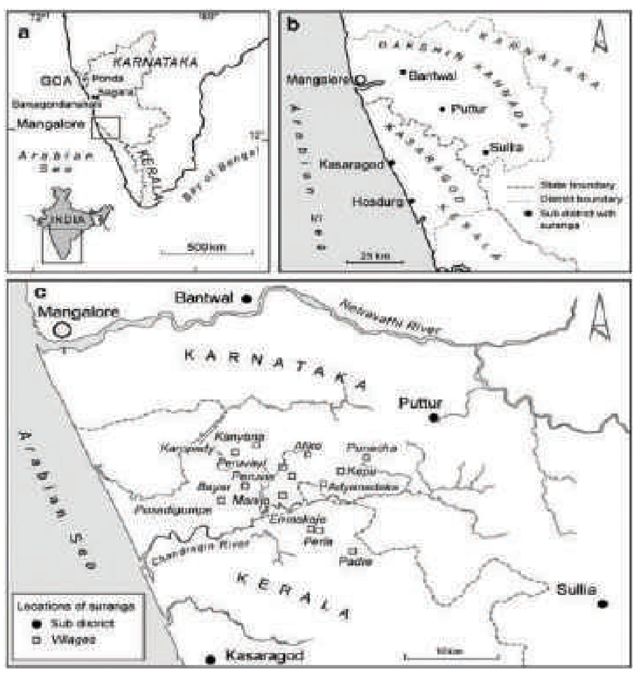
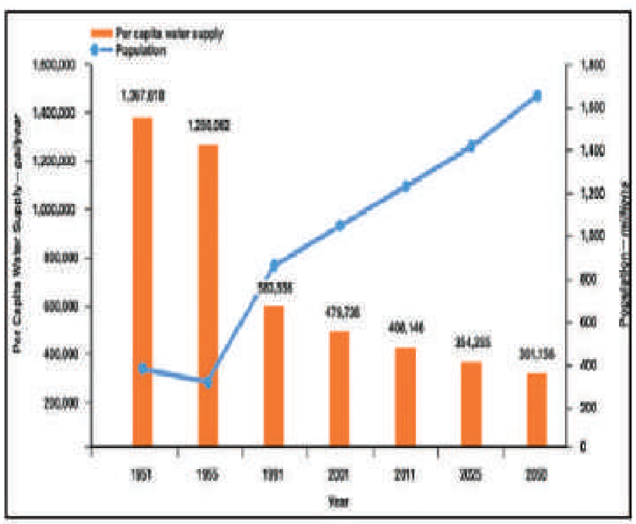


Fig. 2: *Map of the Study where Suranga System are seen*

Surankas are the systems that help in water conservation, which are seen in the western ghats, especially in parts of Kasargod, Dakshin Kannada and very few areas of Goa and they are similar to the qanat technology, which develops a pattern of water conservation along with the water recharging pattern and practice. The study tries to document the details regarding the indigenous water resource management technique of Surangas. Through the study, it particularly tries how the system develops as a solution to the water scarcity issues in Kerala, which in turn leads to the development of sustainable water conservations stratigies.

2. NEED FOR THE STUDY

A lack of water restricts people's ability to get access to clean drinking water and doing basic hygiene chores at home, in institutions, and in medical facilities, claims a UNICEF report. Water scarcity can lead to sewage systems failing, thereby increasing the likelihood of contracting diseases like cholera. Prices are higher for water that is difficult to find. According to the report, four billion people, or more than two thirds of the world's population, suffer from acute water shortages for at least one month out of every year. About 2 billion people reside in nations with insufficient water supplies. By 2025, it's feasible that half of the world's population will reside in regions with poor water access. Due to severe water scarcity, there may be 700 million people on the planet by 2030. One in four kids will reside in places with extremely high-water stress by the year 2040.



high-water stress by the year 2040.

Fig. 3: *KPMG International 2010, Office of Registrar General & Census Commissioner, India*

Humanity is utilising freshwater worldwide due to growing demands for agriculture, industrial, recreation, and drinking water. Maximising the amount of drinkable water from the extremely tiny amount of surrounding water has become a persistent difficulty in numerous settings. The quality and quantity of the environment are taken into consideration whenever administering integrated water resources. Water is recognised as an essential element of the ecosystem. Due to its limited quantity, water can cause problems with distribution. Resource planning is successful when it includes adequate knowledge of the resources that are available, their possible applications, and the competing requirements for those resources; methods and procedures to evaluate the significance and value of those competing priorities; and mechanisms to transform policy choices into actual actions. Traditional wisdom says managing water as a resource is extremely difficult. The objective of the study is to focus on the water conservation techniques and strategies with respect to the Suranga system in Kerala, which in turn can address the water-related issues pertaining to Kerala to a large extent. It addresses an unknown water conservation technique which can be used as a solution for the existing issues regarding water, particularly on matters of surface water and ground water.

3. REVIEW OF LITERATURE

Investments in water management and development had been made in a few Indian districts prior to the establishment of British colonial rule. Historical records, inscriptions, regional customs, and artefacts from the past all support this. In the "*Puranas*", "*Mahabharata*", "*Ramayana*", and other "*Vedic*", "*Buddhist*", and "*Jain*" literature, there are numerous mentions of canals, wells, tanks, and embankments. Pre-colonial *Hindu* and *Muslim* rule in India also refer to governing concepts that were applied to the management of water and were ethical, moral, spiritual, social, and ecological. Ancient religious writings, commentaries, and stone inscriptions all touch on these ideas. The "*Arthashastra*", one of the earliest historical canons authored by "*Kautilya*" in the third century B.C., has extensive descriptions of water management throughout the Mauryan Empire. It claims that the inhabitants had comprehensive knowledge of the various soil types, irrigation methods, and rainfall patterns that were unique to the region's micro-ecological setting. Additionally, according to "*Arthashastra*", the state fostered, helped, and supported minor water harvesting systems throughout pre-colonial Hindu and Muslim authorities throughout

India. The rulers in traditional India issued instructions for the building of various structures for irrigation and water management. To encourage agricultural growth and increase state revenue, Indian emperors encouraged the practise by awarding subsidies to aristocrats, commoners, and even temples to construct tanks.

Referring to water and its management can also be seen in the "*Manusmriti*"(Laws of Manu). Waterworks for the benefit of others find expression in Articles 226 and 229 of Chapter IV. It is the duty of the king to protect the public waters, and for that he can use the services of soldiers and spies (Chapter IX 264–266). Theft or diversion of water is prohibited. Any individual who steals water from an antique tank or terminates the supply must pay the first (lowest) liability. (Chapter IX, 281). Polluting water by spitting or by throwing something impure into rivers (water) is also not encouraged (Chapter IV 46, 48, 56), as it is punishable, and the destruction of embankments is illegal. The sacred thing is that the law clearly states that water bodies of enemies cannot be destroyed during times of war. These Hindu laws were followed until the tenth century, when Islamic rulers took over as rulers of India. It is quite natural that Islamic laws will be followed during their regime. Islamic principles exhort that "water is a gift of Allah (God); no individual or ruler can own water, and everyone should have access to water." In the broadest sense, this implies that everyone, including people and animals, has the right to slake their thirst wherever there is water. (Manu & G. Buhler (Translator), 1886)

The codification of law in India on modern lines goes back to the colonial rule in India. The same was codified by Lord Macaulay, the law member of the Governor General's Council, in 1860, known as the Indian Penal Code. The Penal Code has devoted a separate chapter (Chapter XIV) to offences affecting public health, safety, convenience, decency, and morals. The sections of direct concern are 272, 273 and 277; and sections 268, 269, 270, 271, 278, 280, 282, and 283 are in one way or another related to water or navigation. According to Section 277, whoever wilfully taints or fouls the water of any public spring or reservoir to render it less suitable for the purpose for which it is normally used is subject to a sentence of imprisonment not to exceed three months, a fine not to exceed Rs. 500, or both. According to Section 278, creating an unsafe atmosphere is penalised by a fine.

Section 273 deals with the sale of poisonous food or drink, while Section 272 deals with adulterating food or drink that is intended for sale. Section 268 covers public nuisance, and Sections 280 to 283 are related to navigation. In the course of time, amendments were made to these sections, and new laws were made to supplement these provisions. (*The Indian Penal Code*, n.d.)

India's National Water Policy blatantly adheres to the Dublin perspective; water has economic value in all of its competing uses and ought to be recognised as a good for the economy. The National Water Policy of 2002 calls for the cost recovery principle in water allocation. Section 11 says that:

"There is (therefore) a need to ensure that the water charges for various uses are fixed in such a way that they cover at least the operation and maintenance charges of providing the service initially and a part of the capital costs subsequently." These prices ought to be precisely proportional to the calibre of the services rendered.

A significant policy reversal was necessitated from 2002 onwards. From a substantially subsidised water supply system, there began the pricing of water. In a very fast fashion, Section 11 of the Water Policy was implemented. For instance, under the Swajaldhara guidelines from 2003, water consumers are required to shoulder both complete operational and maintenance responsibilities as well as a portion of the construction cost of new drinking water infrastructure. Encourage private sector active participation in the planning, advancement, and the management of water resources was called for in Section 13 of the Policy (2002) because it was thought that doing so might introduce innovative ideas, determine the capacity, introduce corporate management, and improve service effectiveness and user accountability (Sec. 13). The depiction of water as an economic good, which started with the National Water Policy of 2002, got concretised with the draught water policy of 2012.

The Government of India in February 2012 came up with its new "Draft Water Policy", which speaks about the market environmentalist principle in water supply. Section 7 of the policy says: "Over and above the pre-emptive uses for sustaining life and ecosystems, water needs to be treated as an economic good and, therefore, may be priced to promote efficient use and maximise value from water."

The second part of Section 7 needs to be noted separately:

"While the practise of administering prices may have to be continued, economic principles need to increasingly guide the administered prices."

As per Section 7.2

“There should be a mechanism in every state to establish a water tariff system and fix the criteria for water charges based on the principle that the water charges shall reflect the full recovery of the cost of administration, operation, and maintenance of water resources projects. “The policy also calls for reversing subsidies as “heavy under-pricing of electricity is leading to wasteful use of both electricity and water” (Section 7.5). The positive aspects of the policy include accepting the principle of public trust (Sec. 2.2)”... water needs to be managed as a community resource held by the state, under the public trust doctrine...” and the importance given to local participation in water recharge and flood control. (Government of India Ministry of Water Resources, 2002, 2012).

The nation’s approach to managing its water supply has undergone a major change. The nation has a variety of long-standing customs and procedures for water distribution and conservation that are closely related to the terrain of the area. In this view, access to water was not just restricted to humans but also to all other naturally occurring living things. Such a balance was upset by the emergence of colonial water management laws and practices, the effect of which is still evident today. In their place, geographically and culturally inappropriate policies were imposed on the local population, which led to the destruction of local regulations and guidelines that were based on sustainable water resource management. The nation’s water resource situation became unbalanced as a result.

Due to globalisation, water is now recognised as an economic good in India’s draught water policy. Since the founding of the country, all the way back to the Indus Valley Civilization, this has been outside of the accepted norm. As a result of Chandragupta and Asoka, the nation’s Great Kings and Emperors, the state is currently abdicating its essential responsibility of providing its population with access to clean drinking water. The administration is still adhering to the colonial framework that sought to “absorb the maximum from the Ganges to press them into the banks of the Thames,” shedding all these culturally significant customs and behaviours.

The Surankas’ system is comparable to Persia’s qanat technique. A quant extracts water from subterranean mountainous sources which are trapped in and beneath the upper reaches of alluvial fans using a network of gently sloping tunnels that are frequently several kilometres long. These tunnels subsequently transport the water to the regions where it is needed for household and agricultural purposes. Most likely developed in Iran between 2,500 and 3,000 years ago, the technique of quants eventually spread to Afghanistan and Egypt. Although new qanats are no longer routinely built, many historic administrators can add that they are still in use in Iran and Afghanistan, especially for irrigation.

4. METHODOLOGY

The study uses a case study methodology in which the researcher collects data on a man-made horizontal well or cave that was dug out of dense laterite soil formations and from which water seeps and flows out of the tunnel to be collected in open ponds.

Five respondents have been taken as samples for the current study who built the water conservation technique “Suranga.” The study area was the Kasargod District of Kerala. The details regarding the functioning, structure, and maintenance of the water conservation technique were discussed with the expertise. The data was collected through the Interview Schedule method from the respondents.

5. RESULTS AND DISCUSSIONS

The Indian Western Ghats are home to Suranga. To meet the community’s water demands, borewells are increasingly taking the place of surankas, one of Kasaragod district’s (Kerala) most obscure and rapidly disappearing indigenous water gathering technologies. Similar to horizontal wells or caves carved through solid laterite soil formations, surankas allow water to leak out and flow out of the tunnel to pool in open ponds. Despite being in decline, many farmers in Kasargod still rely on surankas to supply them with drinking water. It is imperative to spread awareness about preserving and revitalising these historic water collecting methods, which are not only far more long-term sustainable than borewells but also have remnants of earlier understandings of how to treat nature with respect and manage its resources wisely.

Suranka is described as man-made horizontal adit systems that are carved into slopes to obtain groundwater for irrigation and consumption. Suranga has a wide range of names. It is important to note that Suranka is known by a variety of other names, including “*Surangam”*, “*Thurangam”*, “*Thorapu”*, and “*Mala”*, due to the linguistic diversity of the area. Suranaka is one of several historic, conventional water harvesting methods that can be found in this region of southern India. The most popular of these are farm pond and tank irrigation, which can be utilised on various scales to store water during periodic water shortages. Suranga is frequently used in conjunction with these water harvesting devices. Because of the extensive history of trade and cultural exchange between Malabar and Persia, modern theories regarding the genesis of this traditional technique suggest that suranga construction was significantly impacted by Qanat technology derived from the Arabian/Persian Gulf region.

The peculiar traditional water harvesting systems used in the Kasargod district, which included surankas or surangams, were among its most important and little-appreciated characteristics. In several regions of the country, traditional water harvesting methods have been developed for a lengthy period of time and have been handed down through the generations. However, it is regrettably being ignored and is most likely going to slowly disappear over the coming years.

Farmers' concerns with water scarcity can be solved very simply, conventionally, and successfully using traditional water fetching techniques. They also build on the long-term ideas of resource allocation, ownership, choice, and sharing in the community. Because the institutions that supported these water collection buildings seem to have disappeared and very few people possess the building skills necessary to erect such structures, it is increasingly likely that this indigenous knowledge will be lost to history.

Due to the geology, which has a huge discharge during the monsoon and a smaller flow during the dry season, residents in Kasargod district in north Kerala cannot rely solely on surface water. Here, residents must rely on groundwater and use specially designed water-gathering devices called Surankas or Surangams. Up until a significant amount of water is hit, the excavation will continue. The tunnel is drained by water that seeps through the compacted dirt. Usually, an open pond built outside the suranga is used to collect this water. A suranga can range in length from 10 to 300 metres and is normally 0.45-0.70 metres (m) wide and 1.8-2.0 metres (m) tall. In other instances, a number of secondary surangams are housed inside the main one. For extra internal pressure when the suranga is very long, several vertical air shafts are inserted. Each next air shaft is spaced 50 to 60 metres apart. The air shafts have dimensions of around 2 m by 2 m, and their depth varies from one spot to another. A suranga almost always requires upkeep, therefore the original cost of digging it could be between Rs 100 and Rs 150 for every 0.72 m. traditionally, a suranga is excavated very slowly and takes generations to finish. Digging for suranga is a highly specialised activity that is only done in the summer. The unit of measurement is the kolu. The respondents claim that it is difficult to find experienced labourers today to dig a suranga. We must make sure there are no plants in the suranga and maintain its cleanliness. Occasionally, crabs can be a very serious hazard.

Table 1: Spatial Distribution of Surangas

State	District	Sub-District	Villages (estimated Number of Surangas)
Karnataka	Dakshin Kannada	Bantwal	Manilla(~300), Pervai Alike, Kanyana,Keropady, Kepu, Punacha
		Sullia	4
		Puttur	8
	Shimoga	Sagara	Banjagaru(4)
Kerala	Kasargod	Kasargod	Bayar, Possadigumpe (~2000), Enmakaje, Adyanadaka, Perla, Padre
		Hosdurg	Kahnangad
Goa	North Goa	Ponda	Priol

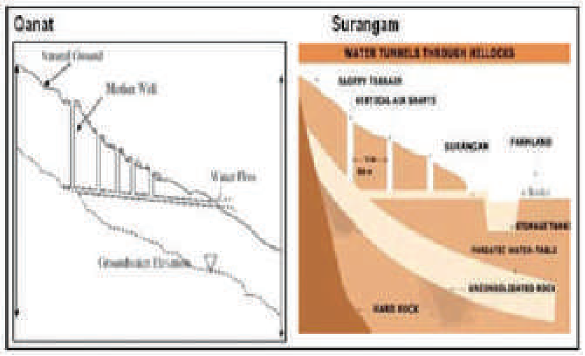


Fig. 4: *Structure of Qanat and Surangam*

Fig. 5: *Outside View of Suranga*

Fig. 6: *Outside View of Suranga*

Fig. 7*: Outside View of Suranga*

People construct surankas using this age-old skill that has been handed down from one generation to the next. The water flow is determined by the slope and elevation, the growth of some hydrophilic plants like "dhoopada mara" ("Vateria indica"), "basari mara" ("Ficus virens"), and "uppalige mara" ("Macranga indica"), "termite mounds", and the soil's texture. In order to find the presence and direction of the flow of the water at night, skilled workers can also detect it by pressing their ears to the ground. Water dowsing and witchcraft are both regularly employed to locate water flow.

Once the flow has been identified, the villages themselves or manual workers use improvised digging implements like pickaxes and wedges to begin digging the surankas. To avoid the wall from collapsing owing to soil moisture, the digging is primarily done between February and May, which is the dry season. The tunnels are often rectangular or dome-shaped, with the right height and width for a man to comfortably work and move through them. The tunnels are built with a downward slope to take advantage of gravity's pull to collect water that is percolating outside. Walls are coated during construction to save them from collapsing from soft or loose soil. Although a suranga can be as deep as 250 metres (820 feet), the average suranga is 26 metres (85 feet) deep. Longer surankas have air shafts built into them to provide fresh air and remove toxic pollutants. The surankas may be connected to one another or may exist independently. A temporary mud barrier or dam can then be used to collect the water, which can then pass through a conduit made of plastic or bamboo and into a pit or tank for storage. Water is transported to the crops using syphon technologies, aqueduct construction, drip irrigation, or other irrigation techniques after being collected in the storage pit.

There is a significant shortage of labourers with the necessary skills to undertake the taxing task of digging it. The fact that young people are hesitant to pursue it as a profession has also exacerbated the problem. The majority of the Surankas are associated with farming households. The conventional system is most preferred due to the region's laterite topography and the residents' conviction that suranga water is cleaner than typical well water. Both conventional and contemporary water harvesting techniques are used in tandem to provide individual farmers with the greatest access to water for irrigation and consumption. The utilisation of farm ponds for retention and storage along with surface and groundwater harvesting maximises the water security for these otherwise vulnerable farmers, allowing them to endure times of drought and extreme heat, excluding the worst-case scenario.

6. CONCLUSION

Water is necessary for both our survival and a healthy, happy life. Everybody needs to wake up and understand how important water conservation is. In other words, the human species could not survive in a world without water. All plants and animals fall under this same category. The absence of water will harm the entire planet. First, the vegetation will soon disappear. Without water, all the vegetation on earth will perish and become a desolate landscape. Different seasons won't exist for much longer. The entire planet will experience one very long summer.

The Suranka system works as not only a water discharging system, but it also works as a water recharging system, so it can address the water conservation and management issues in the same geographical zones. Traditional water collection methods offer a very simple, conventional, and proven solution to the water scarcity problems facing farmers today. It is also based on the concepts of sharing, ownership, choice, and fair and reasonable use of resources over time. This traditional knowledge is likely to be lost at some point in history. The institutions that underpinned these water catchments have disappeared, and those who possess the building skills necessary to build these structures there are few.

Additionally, aquatic species will lose their habitat. That implies people will not be able to view any fish or whales. Most significantly, if people are not aware of the importance of water conservation, all types of living things will become extinct from the surface. Hence, it is imperative to immediately stop wasting water unnecessarily. To save water and regain equilibrium, everyone must put forth effort, and government and non-government organisations should take more initiative regarding this.

7. REFERENCES

Crook, D., Sudhir, T., & Richard, J. (n.d.). *The Sustainability Of Suranga Irrigation In South Karnataka And Northern Kerala, India*.

Government of India Ministry of Water Resources. (2002). *National Water Policy 2002*.

Government of India Ministry of Water Resources. (2012). *National Water Policy (2012)*.

https://www.mei.edu/publications/harvesting-water-and-harnessing-cooperation-qanat-systems-middle-east-and-asia

https://www.statista.com/chart/26140/water-stress-projections-global/

https://www.unicef.org/wash/waterscarcity#:~:text=Half%20of%20the%20world's%20population,of%20extremely%20high%20water%20stress.

Manu, & G Buhler (Translator). (1886). *Laws Of Manu: Vol. Xxv* (F. Max Muller, Ed.). Oxford.

Tarlock, A. D. (n.d.). *Integrated Water Resources Management: Theory And Practice*.

The Indian Penal Code. (n.d.).

Tropp, H. (2007). Water governance: Trends and needs for new capacity development. *Water Policy*, *9*(SUPPL. 2), 19–30. https://doi.org/10.2166/wp.2007.137

Chlorination of Public Water Supply: Risks and Remedies

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Abstract: *This review paper analyzed the risk associated with chlorinating public water supplies and recommends preventative measures to reduce those risks. The article addresses- Risks to public health and safety associated with drinking water, Occupational health risks of the water work operators, Serious cost consequences from frequent operational breakdowns, repairs, and replacements having serious financial implications and Recommendations to solve the aforementioned issues. This paper is aimed to serve as an operational guide for professionals engaged in administration, decision-making, approval, planning, procurement, and execution of public water supply disinfection activities. This will also help scientists, consultants, operators, owners, and government agencies in upgrading the water quality of existing water supplies.*

Key Words: *Calcium Hypochlorite, Chlorination, Corrosion, Scaling, Sodium Hypochlorite.*

1. INTRODUCTION

The issue of water contamination is a never-ending challenging task. During the 1920s and 1930s, many people perished from illnesses including cholera, typhoid fever, and amoebic dysentery that are spread by contaminated water (Mohsen et al., 2019). In order to combat waterborne diseases, different disinfection methods were used to inactivate pathogens. One of the most significant developments in water management of the 20th century can be seen in the use of chlorine to disinfect drinking water (Cmest, H. 2000). Along with other water treatment processes such as coagulation, sedimentation, and filtration, chlorination creates water that is safe for public consumption.

2. BENEFITS

Chlorination has been utilized continuously since its inception more than a century ago. It is a chemical disinfection process that uses different kinds of chlorine or chlorine-containing materials to oxidize and disinfect the water source that will be used for drinking.

Chlorination has the following advantages:

- Proven reduction of most bacteria and viruses in water
- Residual protection against recontamination
- Scalability and low-cost
- Ease of use and acceptability
- Proven reduction in the incidence of diarrheal illness

Chlorine was introduced as a disinfectant to the urban water supply in the beginning of the 20th century to eliminate waterborne bacterial pathogens and prevent the consequent transmission of waterborne diseases. Because of chlorine disinfection, a drastic reduction in the incidence of waterborne diseases, for example, cholera, typhoid fever, and dysentery was achieved. The near-universal adoption of chlorine and its various forms for water disinfection can be attributed to its convenience and highly satisfactory performance. Further, chlorination chemicals are relatively readily available, inexpensive, and easy to apply. Alternative chemicals disinfectants such as chloramine (chlorine reacted with ammonia), chlorine dioxide, ozone, and ultraviolet radiation have also been used but to a much lesser extent (Nieuwenhuijsen et al. 2000).

In drinking water treatment plants, chlorine is either used as chlorine gas, sodium hypochlorite solution, or as solid calcium hypochlorite (including bleaching powder). Elemental chlorine is a toxic, yellow-green gas at normal pressures, and at high pressure, it is a liquid. Gaseous chlorine, when added to water, rapidly hydrolyzes to hypochlorous acid (HOCl) and hydrochloric acid (HCl) as follows:

$Cl_2+H_2O \rightleftarrows HOCl+H+Cl^-$

$HOCl \rightleftarrows H^++OCl^-$

The relative concentrations of hypochlorous acid and hypochlorite ion are dependent on the pH and the temperature. Generally, hypochlorous acid is a better disinfecting agent than hypochlorite ion (Askenaizer 2003).

Calcium hypochlorite is available as a white powder, pellets, or flat plates which contain 65-70 % available chlorine. It decomposes readily in water or when heated, releasing oxygen and chlorine. Calcium hypochlorite is a corrosive material with a strong odor. It is not flammable, although it acts as an oxidizer and may react explosively with ammonia, amines, or organic sulfides. Calcium hypochlorite readily absorbs moisture, forming chlorine gas. Hence, calcium hypochlorite should be stored in a dry, well-ventilated area at a temperature below 50 °C away from acids, ammonia, amines, and other oxidizing agents. Calcium hypochlorite is also toxic to aquatic life. Calcium hypochlorite dissolves easily in water but often forms a precipitate in hard water supplies (Askenaizer, 2003).

Sodium hypochlorite is easier to handle than chlorine gas or calcium hypochlorite. Sodium hypochlorite is generally sold in aqueous solutions containing 5 to 15 % chlorine, with 0.25 to 0.35 % free alkali (usually NaOH) and 0.5 to 1.5 % NaCl. Sodium hypochlorite can be generated on-site by using electrolysis of sodium chloride solution. Hydrogen gas is given off as a by-product and must be safely dispersed. This solution is a clear, greenish-yellow liquid with an odour of chlorine. It is, however, extremely corrosive and should be kept away from equipment that could be damaged by corrosion. Sodium hypochlorite solutions can liberate dangerous amounts of chlorine or chloramine if mixed with acids or ammonia. Anhydrous sodium hypochlorite is very explosive and should not be stored for more than 1 month at a temperature not exceeding 20 °C, away from acids and sunlight, in air-tight bottles (Askenaizer 2003).

Fig. 1: *Internal corrosion and clogging of different water pipes*

3. DRAWBACKS

Disinfection of municipal water by chlorine and non-gaseous chlorination chemicals has given significant community health advantages by preventing water-borne diseases. Despite its role in disinfection, hypochlorite powder, solutions, and vapour are irritating and corrosive to the eyes, skin, and respiratory tract. Asthma, allergies, and sinus issues are made worse by exposure to chlorine vapour (Mohsen et al., 2019). Skin contact produces injury to any exposed tissues primarily due to the corrosive properties of the hypochlorite moiety. Hypochlorite causes tissue damage by liquefaction necrosis resulting in burning pain, inflammation, and blister. Fats and proteins are saponified, resulting in deep tissue destruction. Further injury is caused by thrombosis of blood vessels. Calcium hypochlorite and Sodium hypochlorite solutions liberate toxic gases chlorine or chloramines. Direct eye contact with hypochlorite solutions, powder, or concentrated vapour causes severe chemical burns, leading to cell death and ulceration. Ingestion of hypochlorite solutions causes vomiting and corrosive injury to the gastrointestinal tract. Household bleaches (3 to 6 % sodium hypochlorite) usually cause esophageal irritation (https://www.atsdr.cdc.gov/).

3.1 Corrosion & Scaling

Internal corrosion and scaling process is ubiquitous and occurs inevitably in new and old metallic pipes of drinking water distribution systems (Figure 1). The corrosion process consists of a series of electrochemical reactions occurring on the metal surface in contact with water. The corrosivity of water depends on its chemical constituents and the hydraulic conditions, as well as the material of the pipe (Leiva-Garcia et al. 2011). Corrosion in residential distribution systems can deteriorate drinking water quality and potentially threaten human health. Some of the consequences of internal corrosion are clogging of pipes with corrosion products, pipe breaks, and water quality deterioration. Corrosion scales formed by the accumulation of corrosion products could serve as the breeding ground for microbes and sinks for heavy metals or other contaminants (e.g. arsenic, vanadium, lead). Disturbance of corrosion scales or biofilm might result in odor, bad taste, discolored water episodes, microbial film loosening and sorbed contaminants release (Yang et al. 2012). Thus, research on corrosion and the corresponding scale formation is useful for global water industries.

Chlorine is widely used for its strong oxidizing action as a disinfectant to inactivate microbial contaminants in water purification processes. Water supply systems aim to maintain at least a minimum level of residual chlorine, in order to prevent possible microbial regrowth and the spread of waterborne diseases. However, the presence of excessive levels of disinfectant caused negative effects on the consumer's health and is an important factor that accelerates the corrosion of the pipes (Garcia-Avila et al. 2019).

4. SCIENTIFIC ENDORSEMENTS

The corrosion and scaling properties of this chlorine compound and their serious damaging effects have been adequately endorsed by several scientific observations, a few of which are as under:

Corrosion caused by high levels of residual chlorine decrease in the strength of the pipes that transport potable water can cause adverse effects on water quality and serious failures in the infrastructure of the supply network (Garcia-Avila et al. 2019). This process has many negative effects on the drinking water supply, such as hydraulic capacity reduction, water quality deterioration, pipe material destruction, and microbial proliferation (Zhang et al. 2020).

Chloride and sulfate are well known corrosive ions, which can break the scale, leading to the release of iron chemicals resulting in red or yellow water. An increase in chloride and sulfate accelerated the corrosion process (Zhang et al. 2020). Calcium hypochlorite tends to deposit scale on piping system and equipment that convey hypochlorite solution; this must be addressed in disinfection system design and system maintenance. The calcium in the water reacts with dissolved CO_2 resulting in the formation of calcium carbonate scale. In some instances, the 2-inch pipes have turned into 3/4-inch pipes due to scale build up (Frank 2013). In addition, the presence of calcium hypochlorite increases the corrosion rate of metallic pipes (Leiva-Garcia et al. 2011). Further, disposal of chlorine containing sewage may accelerate degradation of metal, subsequently leading to increase in corrosion even after the treatment process (Romanovski et al. 2020)

An increase in corrosion can be expected when free chlorine is introduced for disinfection into a drinking water system. Iron appears to be the most affected by free chlorine addition, followed by copper and lead (Cantor et al., 2003). In the case of Lead and Zinc, the addition of calcium hypochlorite produces an increase in the corrosion rate of both metals. Metal leaching from water pipes, mostly lead dissolution, is the main cause of drinking water contamination in many countries, thus endangering public health (Leiva-Garcia et al. 2011).

Copper concentrations in drinking water distribution systems were shown to be related to the free chlorine concentration. In particular, the coupon corrosion tests reasonably predicted the effect of chlorine on copper solubility. The calcium content hardens the water and tends to clog up filters. Localized corrosion such as pitting and crevice corrosion of stainless steel can occur in the presence of calcium hypochlorite. Calcium hypochlorite is best kept in a cool dry place away from any organic material. It is known to undergo self-heating and rapid decomposition accompanied by the release of toxic chlorine gas, which is highly corrosive (Garcia-Avila et al. 2018).

Such scale and corrosion are proven causes of increased operational and maintenance activities & costs which can be evidenced by the large number of tender inquiries involving frequent repairs and replacements of pipelines and accessories as well as the chlorine dosing systems.

5. SEVERE RISKS COMPROMISING THE HEALTH-SAFETY OF THE PUBLIC: EVIDENCES

A large number of cases involving gastro diseases and deaths have been frequently reported from various corners of India due to leakages in pipelines as a result of severe corrosion. However, the most tragic incident in recent years took place in Flint, Michigan in the United States of America, and is widely known as the Flint Water Crisis (Figure 2). This is a public health crisis that started in 2014 after the drinking water for the city of Flint, Michigan was contaminated with lead and possibly Legionella bacteria. In April, 2014 residents complained about the taste, smell, and appearance of the water. Officials failed to apply corrosion inhibitors to the water, which resulted in lead from aging pipes leaching into the water supply, exposing around 100,000 residents to elevated lead levels. A series of major water quality and health issues for Flint residents involved foul-smelling, discolored, and off-tasting water piped into Flint homes for 18 months causing skin rashes, hair loss, and itchy skin.

Elevated blood lead levels in the city's children, imperiling the health of its youngest generation. The crisis witnessed the third-largest outbreak of Legionnaires' disease recorded in U.S. history that killed 12 and sickened at least 87 people between June, 2014 and October, 2015. Fecal coliform bacteria were identified in city water. Ironically, the city's corrective measure—adding more chlorine without applying corrosion inhibitors and addressing other underlying issues—created a new problem: elevated levels of TTHM, and further leaching of lead from pipes (Masten et al. 2016).

6. GLOBAL REGULATORY FRAMEWORK

In the USA, under the 1991 federal lead and copper rule (LCR) and its revisions, large and certain small water systems must recommend to the Safe Drinking Water Act primacy agency (usually the state) an optimum corrosion control treatment (OCCT). Federal regulations at 40 CFR 141.2 define the "OCCT" as "the corrosion control treatment that minimizes the lead and copper concentrations at users' taps. Similarly, the new European Directive includes a severe reduction of the parametric value concerning lead in drinking water. The World Health Organisation, in the Third Edition of Volume 1 (Recommendations) of "Guidelines for Drinking-water Quality" has specifically highlighted the following:

- Water treatment should be optimized to prevent microbial growth, corrosion of pipe materials and the formation of deposits
- Corrosion control is therefore an important aspect of the management of a drinking-water system for safety.
- All other practical measures to reduce total exposure to lead, including corrosion control, should be implemented.

The Central Public Health & Environmental Engineering Organisation (CPHEEO) under the Ministry of Housing and Urban Affairs, Government of India, has indicated in Chapter 9 of Manual on "Water Supply and Treatment" (1999 edition) that excessive residual chlorine may increase the corrosiveness of water.

7. STORAGE & TRANSPORTATION

Storing & transporting raw calcium hypochlorite granules (CHG) is a proven source of severe accidents and fire hazards. Calcium hypochlorite is a cargo that has been linked to a number of serious casualties, including the CMA DJAKARTA, DG HARMONY and CONTSHIP FRANCE. Very recently in May, 2019 flames ripped through a load of cargo including chemicals in Thailand's eastern Laem Chabang port, forcing officials to evacuate workers and temporarily close three piers. More than 130 people were taken to the hospital. Red flames and clouds of thick black and white smoke poured out of the South Korean container ship KMTC Hongkong Co. Initial checks showed the blaze broke out in a load of cargo containing the chemical calcium hypochlorite. In the case of ACONCAGUA: the entirety of the cargo was destroyed by the initial fire and explosion on December 30, 1998.

Calcium hypochlorite is no stranger to controversy. The chemical has been cited in a handful of fires and emergency incidents in the past several years. Most notable was a March 2004 blaze at a Bio-lab warehouse in Georgia that burned for two days and forced the closure of a major Atlanta interstate. Bio-Lab is home to 250,000 lbs of calcium hypochlorite.

8. HANDLING

Inhalational and dermal injury due to the explosion of calcium hypochlorite has also been reported. A case of chlorine toxicity and burns on a man's face due to the explosion of calcium hypochlorite while mixing it into the water was reported in 2009 (Yigit et al. 2009). Inhalational and cutaneous injuries as a result of the explosion of calcium hypochlorite have also been documented (Vohra and Clark 2006).

In many swimming pools, calcium hypochlorite is utilized as a disinfectant form. The kind of chlorine chosen relies on a variety of elements, including price, availability, equipment upkeep, and simplicity of use. For instance, hypochlorite salts are more expensive than chlorine gas, which is less expensive but more challenging to use. It is challenging to move and store sodium hypochlorite in liquid form (Yigit et al., 2009). Because calcium hypochlorite is portable and can be kept in storage for a long time, rural and small-community water sources are where it is most frequently employed. When it comes to the pathophysiology, clinical manifestation, and treatment options for chlorine inhalation injuries, there is a lot of disagreement in the literature, especially when it comes to the inhalation of steroids and bicarbonate (Sexton and Pronchik 1998).

When handling calcium hypochlorite, the pump house operators run a very significant danger of chronic exposure to chlorine fumes. In its Hazard Summary, the New Jersey Department of Health and Senior Services classified calcium hypochlorite as a dangerous material as follows (Schonhofer et al. 1996):

- When breathed in, calcium hypochlorite can have an impact on you.
- The skin and eyes can be badly irritated and burned by contact.
- The throat and nose can become irritated when breathing calcium hypochlorite.
- Calcium hypochlorite can irritate the lungs, which can lead to coughing and/or shortness of breath when breathed in. Higher exposure levels have the potential to result in pulmonary edema, a medical emergency characterized by extreme breathlessness.

9. IDENTIFICATION OF SOURCES OF THE PROBLEMS & THEIR SOLUTIONS

The problems associated with calcium hypochlorite stem from the following causes to which the recommended solutions have also been indicated below:

- Packing size of the drums which contain the chemical: The higher the quantity in the drums, the more the risk of fire and explosion. Problems have been identified even with pack sizes of 45 kg – 50 kg. Reduction of packing size to 3 kg, 5 kg, etc. greatly reduces this problem.
- Corrosion & scaling properties: This is a major drawback of calcium hypochlorite which can be addressed by using chlorination chemicals fortified with CIAS.
- Critical Ambient Temperature (CAT): The CAT of calcium hypochlorite is as low as 40 ºC – 60 ºC which is the major cause of fires and explosions involving

this chemical. The addition of corrosion inhibitors and anti-scaling agents largely reduces this problem.

- High Chlorine concentration (strength): Calcium Hypochlorite is usually available in very high strengths of 60 % - 70 % free chlorine resulting in several issues involving storage, transportation and handling of this chemical. Lowering the strength of the chemical of the chemical to 40 % - 50 % or blending with CIAS can overcome such problems.
- Operator exposure (occupational hazard): Chronic exposure to the chemical needs to be prevented by ensuring packaging in contactless exposure-free non-metallic dispensers.

10. RECOMMENDATIONS

In view of the above, it is recommended that chlorination with non-gaseous chlorine compounds (such as Bleaching Powder, Sodium Hypochlorite and High Strength Bleaching Powder/ Calcium Hypochlorite) should be practiced only when such chlorination chemicals are fortified with CIAS since these chlorine compounds cause scaling and corrosion, pose serious risk compromising health-safety of water consuming public, and are a proven source of severe accidents that have caused disease / death / disability during storage, transport and handling. Such problems associated with the regular use of these non-gaseous chlorine compounds also result in an associated huge drain of operation and maintenance funds which can be overcome by fortifying them with CIAS with proven techno-commercial superiority.

Several International scientific publications have endorsed such disinfectant formulations containing scale inhibitors to minimize scaling and associated operations and maintenance (O&M) burdens. However, the presence of CIAS in the formulation must be checked with CIAS spot test kits for confirmation rather than relying solely on self-declaration by the OEMs or laboratory certificates. Since several safer and techno-economically feasible options are now available as discussed above, it is strongly recommended that the use of raw unblended High Strength Bleaching Powder as an alternative treatment technology in community drinking water supplies and calcium hypochlorite be discontinued for reasons indicated in the previous paragraphs.

11. REFERENCES

Askenaizer D. (2003). "Drinking Water Quality and Treatment." *Encyclopedia of Physical Science and Technology* (Third Edition): Academic Press, 651-671.

Cantor A.F., Park J.K. and Vaiyavatjamai P. (2003). "Effect of cholorine on corrosion in drinking water systems." *J. Am. Water Works Assoc*., 95(5):112–123.

Cmest H. (2000). "The public health consequences from swimming pool chlorinator tablets." *J. Occup. Environ. Med*., 44(10): 906-13.

Frank R.S. (2013). "Handbook of Water and Wastewater Treatment Plant Operations." Third Edition, CRC Press, *Technology & Engineering.*

Garcia-Avila F., Bonifaz-Barba G., Donoso-Moscoso S., Del Pino L.F. and Ramos-Fernandez L. (2018). "Dataset of copper pipes corrosion after exposure to chlorine." *Data Brief*, 19(19): 170-178.

Garcia-Avila F., Flores del Pino L., Bonifaz-Barba G., Zhindon-Arevalo C., Ramos-Fernandez L., Garcia-Altamirano D., Vazquez-Garcia S. and Sanchez-Alvarracin C. (2019). "Effect of residual chlorine on copper pipes in drinking water systems." *J. Eng. Sci. Tech. Rev*., 12 (2): 119 – 126.

Leiva-Garcia R., Munoz-Portero M.J. and Garcia-Anton, J. (2011). "Influence of calcium hypochlorite on the corrosion behaviour of metal components of residential water pipes." *In International Conference on Energy Environment Entrepreneurship Innovation ICEEEI11*, 76-81.

Masten S.J., Davies S.H. and Mcelmurry S.P. (2016) Flint Water Crisis: What Happened and Why?, *J. Am. Water Works Assoc*., 108(12): 22-34.

Mohsen I.H., Mohsen A.H. and Zaidan H.K. (2019) Health effects of chlorinated water: A review article, *Pakistan Journal of Biotechnology*, 16(3): 163-167.

Nieuwenhuijsen M.J., Toledano M.B., Eaton N.E., Fawell J. and Elliott P. (2000). "Chlorination disinfection byproducts in water and their association with adverse reproductive outcomes: a review." *Occup. Environ. Med.,* 57(2): 73-85.

Romanovski V., Claesson P.M. and Hedberg Y.S. (2020). "Comparison of different surface disinfection treatments of drinking water facilities from a corrosion and environmental perspective." *Environ. Sci. Pollut. Res*., 27: 12704–12716.

Schonhofer B., Voshaar T. and Kohler D. (1996). "Long term lung sequelae following accidental chlorine gas exposure." *Respiration*, 63: 155–9.

Sexton J.D. and Pronchik D.J. (1998) Chlorine inhalation: the big picture, *J. Toxicol. Clin. Toxicol*., 36(1–2): 87–93.

Vohra R. and Clark R.F. (2006). "Chlorine-related inhalation injury from a swimming pool disinfectant in a 9-year-old girl." *Pediatr. Emerg. Care*, 22(4): 254–7.

Yang F., Shi B., Gu J., Wang D. and Yang M. (2012). "Morphological and physicochemical characteristics of iron corrosion scales formed under different water source histories in a drinking water distribution system."*Water Res*., 46(16): 5423-5433.

Yigit O., Soyuncu S., Eray O. and Enver S. (2009). "Inhalational and dermal injury due to explosion of calcium hypochlorite." *Cutan. Ocul. Toxicol*., 28(1): 37-40.

Zhang H., Zhao L., Liu D., Wang J., Zhang X. and Chen C. (2020). "Early period corrosion and scaling characteristics of ductile iron pipe for ground water supply with sodium hypochlorite disinfection." *Water Res*., 176: 115742.

Assessment of Potability of Spring Water from Veling, Mardol, Goa, India

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Abstract: *Present study deals with determination of potability of spring water from Veling village. Efforts has made to check any kind of contamination present due to biological, organic and inorganic pollutants. For this purpose Physicochemical analysis plays very important role in understanding and maintaining of this fragile ecosystem, which is essential not only for humans but also for various other life forms, this could also be consider a small contribution to follow good practices of Goal-6 (Clean Water and Sanitation) mentioned in Sustainable Development Goals. The assessment of quality of spring water from "Shri. Laxmi Narshima Sacred Spring Water", Veling village, Mardol, Goa situated in Ponda Taluka, North Goa District, Goa, India, 15º 25' 59" N and 73º 58' 20" E was carried out. Physiochemical parameters were analysed and compared as per water quality standards prescribed by Indian Standard ISI 10500-91. Altogether 20 physicochemical and bacterial parameters were analysed namely pH, colour, temperature, odour, turbidity, total hardness, total dissolved solids, iron, chloride, calcium, magnesium, sulphate, nitrate, total alkalinity, fluoride conductivity, dissolved oxygen, total coliform, E coli and volumetric flow rate. Analysis showed that, two parameters were found beyond prescribed limit set by Indian Standard ISI 10500-91 and WHO, indicating spring water contamination and not fit for human consumption. However, it can be used in future only after essential treatment, also frequent testing and monitoring is suggested to maintain its quality.*

Key Words: *Spring water, Ph, Coliform, DO, Acidic water and Health risk.*

1. INTRODUCTION

It is very much essential to use pollution free and clean water, which means that water must be free of any kinds of chemicals and germs, with no turbidity and should be clear, called potable water or water which is safe for drinking. Non potable water is unsafe for consumption, time witnessed all around the world in the past that, there had been many occasions when hundreds and thousands of people have died, due to disease causing germs had spread through the community by polluted water supply, this type of disease are called Water Borne diseases. In this study efforts have been made to test the potability of spring water from Veling village, Goa, famous as "Shri. Laxmi Narshima Sacred Spring Water" (Patil and Patil 2010; Bui and Lodhi 2020; Chauhan et al. 2020; Hem 1985). Rivers and wells are the main source of water used by humans, which is called surface water. Soil moisture and aquifer are the majority of fresh water, which actually found underground. Humans can use both surface as well as groundwater. Rivers are keep flowing even when there is no precipitation, is due to groundwater feeds the stream. When rainfall infiltrates earth surface it becomes groundwater and due to gravitational force it slowly seeping downwards into extensive layers of soil pores and rocks are called Aquifer. When this flow gets an opening closed to the land surface it is called spring water. Spring water could be any water that originates from an underground aquifer. It is consider to be rich in mineral profile due to natural organic filtration from reliable and safe sources. It is free from harmful Chemicals like Chlorine and microbes and may be because of this, people sometimes considered it with medicinal properties. Minerals present in these waters generally could be Magnesium, Potassium, Calcium and Sodium and some trace minerals, this depends on the surrounding of the rock structure. Spring waters are also important for biodiversity and Ecosystem, they are also responsible for rise of rivers and Wells.

Nowadays they are under continuous threat despite of their importance. Threat from anthropogenic pollution, climate change and over exploitation of the groundwater discharge. Mostly spring waters are perennial, but in future, major threat could be that, it may not remain like that throughout year. And becomes seasonal and may even go dry completely, if not use sustainably, this is due to the reduction in water table. Quality and reduction in water source will have a bad impact on health of regional livelihood and biodiversity, which depends on it. The anthropogenic activity within a spring shade or Catchment area affects the quality of water. To overcome spring water pollution and its protection, development of spring shade is very important. Spring shade can be targeted for protection, restoration and groundwater recharge. Local administrative bodies may take initiatives to monitor and management of the springs. Increase in the vegetation cover, mitigating measures to cease point source and non-point source pollution, reduced soil erosion, increasing infiltration and recharge of aquifer are few of such management techniques can be adopted.

2. METHODS AND MATERIALS

Goa is the smallest state of India having the total area of 3702 sq. km of Indian peninsula, comprising of two districts, namely North Goa and South Goa. It is rich and varied in mineral resources. It is located on Konkan coast i.e. western part of India. To the North, Goa share the border with Maharashtra and South with the Karnataka. Towards West is the Arabian Sea, with coastline of 131 km. Goa mostly has hilly landscape forming Western Ghats at the eastern end with an altitude of 1700 meters from sea level. Western Ghats act like strong wall, due to which Goa receives the annual average rainfall of 340 cm – 450 cm during the South West Monsoon from June to September (Potdar et al. 2019; Metri and Singh 2010). This monsoon is very much responsible to flourish fresh water resources and ground water recharge. It is the reason Goa has many spring water resources along with perennial rivers. Spring waters, are sometimes perennial and sometime emerges according to the rainfall in the surrounding area. We can also say when aquifer being filled to the point, that the water overflows onto the land surface.

For this study, one of such spring water source were selected, area located in North Goa District, in Ponda Taluka. "Shri. Laxmi Narshima Sacred Spring Water", Veling, Mardol, Goa, India (Figure 1 & 2) 15°25'59" N and 73°58' 20" E (Buda and Costa 2013; Google map 2021). Exactly above sampling area Farmagudi plateau exist and on this plateau Goa Engineering College is located. The area of the village is 315 ha, with population is around 1921 persons, as per 2011 census (N. Goa 2011). Village comes under Village Panchyat - Veling Priol Cuncolim. Purpose of selecting this site is because most of the village population use this spring water for drinking and domestic purpose. Also act as an alternative source during the unreliable water supply provided by the government, that is water supplied by the Public Work Department (PWD).Water sample was collected on 30th June 2021 at 09:00 a.m. During the sampling day, the outside-recorded temperature was 27.5 ºC with 80% humidity. The samples were collected in HDPE bottles and BOD bottles for physiochemical and bacterial parameters. Since it was a June month, Goa was under the monsoon season, but the rainfall was absent during the sampling day, it was Sunny with clear sky. Before the collection of the sample, bottles were cleaned thoroughly for multiple times with distilled water and then rinsed with the sample (spring water) for 2 to 3 times. Whereas the BOD bottle used for sampling was sterilized. All together 20 parameters were analysed. Temperature and Volumetric Flow Rate has performed on site. Following parameters has been analysed to test the potability and quality of water.

- Physiochemical Analysis: pH, Colour, Odour, Turbidity, Temperature, Volumetric flow rate, Total Hardness, Total Dissolved Solid, Iron, Chlorides, Calcium, Magnesium, Sulphate, Nitrate, Total Alkalinity, Fluoride and conductivity.
- Biological Analysis: Coliform-MPN/ 100 ml and E, Coli.

Physicochemical and Bacterial analysis for potability of water has done, following are the details of test methods followed for different parameters (Table 1). Results were compared with standards prescribed by ISI 10500-91 (BIS, 2012; WHO, 1963). Temperature and volumetric flow rate was analysed using thermometer and bucket test on site. 20 litres of bucket was placed underneath of the spring water and with the help of the digital stopwatch, the time has recorded. With the help of the following formula, volumetric flow rate was calculated.

$Q = (V/T) \times 60$

Where,

Q= Volumetric flow rate, V= Volume, T= Time

Table 1: Test methods followed for different parameters as per Indian Standards (BIS: 2012)

Sr. No.	Parameter	Test Method followed
1.	pH @ 25°C	IS 3025 Part 11
2.	Colour	IS 3025 Part 4
3.	Temperature	Thermometer
4.	Odour	IS 3025 Part 5
5.	Turbidity	IS 3025 Part 10
6.	Total Hardness as CaCo3	IS 3025 Part 21
7.	Total Dissolve Solids	IS 3025 Part 16
8.	Iron as Fe	IS 3025 Part 53
9.	Chlorides as Cl	IS 3025 Part 32
10.	Calcium as Ca	IS 3025 Part 40
11.	Magnesium as Mg	IS 3025 Part 46
12.	Sulphates as So4	IS 3025 Part 24
13.	Nitrates as No3	APHA 23rd Edition 4500, NO_3B
14.	Total Alkalinity as CaCo3	IS 3025 Part 23
15.	Fluorides as F	APHA 23rd Edition 4500-F-D, SPADNS Method
16.	Conductivity	IS 3025 Part 14
17.	Dissolved Oxygen	IS 3025 Part 38
18.	Most Probable No. of Coliform Organism- MPN /100 ml	IS 1622:1981 (Reaffirmed 2014)
19.	E. Coli / ml	IS 15185:2016 (Reaffirmed 2018)
20.	Volumetric Flow rate	Using bucket test

3. RESULTS AND DISCUSSION

3.1 Site Specification

The primary physical observation about spring water is that, water flows from the aquifer of about 2.5 meters height on to the surface, falls out from the opening vent called "GOUMUKH" (Figure 3, top right), meaning from 'the mouth of cow' and gets collected in a nearby small pond (Figure 3, Top left). Pond water was clear and no turbidity was observed, the depth of the pond is approximately 1 - 1.5 meters, depth varies as per season. One strange thing observed is that, there was not much presence of fresh water fish in this pond. When I had previously visited this location several times, I had noticed fish in this. But now they were nearly absent, the prominent cause could be, the low level of pH and also lower limit of dissolved oxygen observed during the analysis done (Rose and Long 1988; Jellyman and Harding 2014; Fromm 1980; Leivestad and Muniz 1976). Near to this pond lots of green grasses has grown and because of this, reflection in pond looks greener. But there is no sign of algal bloom or eutrophication, as analysis results shows the detected amount of Nitrate in spring water was very less in quantity.

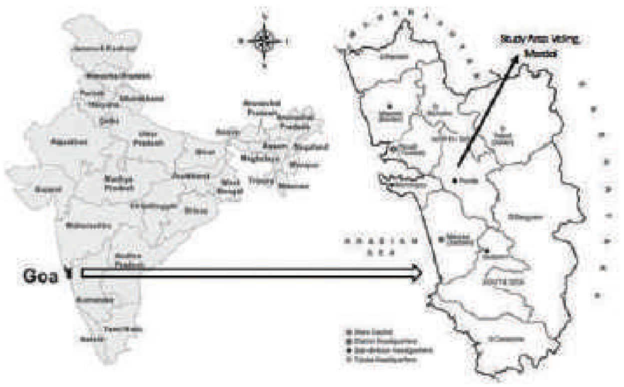

Fig. 1: *Study area map (Buda and Costa 2013)*

Fig. 2: *Top view of study area (Google map 2021)*

Fig. 3: *Top left, picture of studied spring water area along with pond. Top right, is opening vent of spring water called "Goumukh". Bottom left, signboards displayed with various instructions. Bottom right, different flora in watershed region.*

Table 2: Analysis of Physiochemical and bacterial observations of spring water

Observed					Expected (Optimal range for drinking water) as per ISI 10500-91	
Sr. No.	Parameter	Unit	Result	Test Method	Acceptable Limit	Permissible Limit
1.	pH @ 25ºC	-	**4. 88**	IS 3025 Part 11	6.5 – 8.5	No Relaxation
2.	Colour	Hazen	**5.00**	IS 3025 Part 4	5	15
3.	Temperature	ºC	**27**	-	-	-
4.	Odour	-	**Agreeable**	IS 3025 Part 5	Agreeable	Agreeable
5.	Turbidity	NTU	**1.71**	IS 3025 Part 10	1	5
6.	Total Hardness as CaCo3	mg/Lt	**4.00**	IS 3025 Part 21	200	600
7.	Total Dissolve Solids	mg/Lt	**21.00**	IS 3025 Part 16	500	2000
8.	Iron as Fe	mg/Lt	**Not Detected**	IS 3025 Part 53	0.3	No Relaxation
9.	Chlorides as Cl	mg/Lt	**7.00**	IS 3025 Part 32	250	1000
10.	Calcium as Ca	mg/Lt	**0.80**	IS 3025 Part 40	75	200
11.	Magnesium as Mg	mg/Lt	**0.49**	IS 3025 Part 46	30	100
12.	Sulphates as So4	mg/Lt	**0.80**	IS 3025 Part 24	200	400
13.	Nitrates as No3	mg/Lt	**1.84**	APHA 23rd Edition 4500, NO_3B	45	No Relaxation
14.	Total Alkalinity as CaCo3	mg/Lt	**Not Detected**	IS 3025 Part 23	200	600
15.	Fluorides as F	mg/Lt	**Not Detected**	APHA 23rd Edition 4500-F-D, SPADNS Method	1	1.5
16.	Conductivity	µs/cm	**33.60**	IS 3025 Part 14	-	-
17.	Dissolved Oxygen	mg/Lt	**6.90**	IS 3025 Part 38	-	-
18.	Most Probable No. of Coliform Organism- MPN /100 ml	-	**23**	IS 1622:1981 (Reaffirmed 2014)	Shall not be detectable in any 100ml sample	Shall not be detectable in any 100ml sample
19.	E. Coli / ml	-	**Absent**	IS 15185:2016 (Reaffirmed 2018)	Shall not be detectable in any 100ml sample	Shall not be detectable in any 100ml sample
20.	Volumetric Flow rate	Lt/min	**28.14**	-	-	-

The villagers are using this spring water for long time. Mostly it is used for drinking and domestic purpose. It is a major source for drinking and livelihood, for a majority of rural population in Veling village, despite of water supplied from government. Villagers claim that, it has medicinal properties, as water flows through the complex root system, making it rich source of nutrient and mineral. But the observations shows that the spring water is contaminated at the source and unsafe for drinking. Just above the spring water, in watershed area, moderately dense coconut and beetelnut farms were observed with other floral species. (Figure 3, bottom right) The local Temple administration has well maintained and conserve the area to avoid the misuse and keep it away from any sort of water pollution. Sign boards with warnings like "no washing of clothes, no use of soap, no bathing of animals or calves," have been put in place (Figure. 3, Bottom left), although it can only be used for drinking and taking a shower without using soap. If anyone found violating the instructions, will be punished. Also to add more security to this, CCTV cameras has installed, to keep a continuous and closed watch. It is necessary to preserve this natural source of fresh water for the current and next coming generation from the pollution and other anthropogenic activities.

3.2 Analytical Observation

The quality of this spring water and its potability was analysed by examining its physicochemical and bacterial attributes based on "Indian standard, methods of sampling and test (physical and chemical) for water and wastewater" (Standard 2006). The observations for physiochemical and bacterial analysis are as follows (Table 2) along with its detailed test methods and optimal range for drinking water.

The pH at 25ºC has observed here is 4.88, which is beyond the prescribed limit for the drinking water, it is acidic in nature & major concern for villagers, who is consuming this water on daily drinking purpose. Water with low pH levels are more possibly to leach heavy metals from the surroundings (Krol et al. 2020; Saria et al. 2006). Particularly acidic water can be high in concentration of lead, arsenic, copper, nickel, cadmium, chromium, and zinc. Resulting water ends up with a higher concentration of heavy metals. This is alarming, as exposure to heavy metals can be vulnerable, potentially leading to heavy metal poisoning and toxicity in consumers (Jaishankar et al. 2014; Anyanwu et al. 2018; Jan et al. 2015). There could be many reasons for low pH of spring water, for example natural causes like acidic rain, microorganism from surrounding soil, tree roots, and some rock formations can also generate acids leading nearby water system to become acidic. Low in the pH may due to possibility of pre monsoon and initial monsoon rainfall. Here, it rained during cyclone "Tauktae," and the first downpours were always considered acidic in nature (pH less than 5.6). As the water droplets reacts with the CO_2, NO_X and SO_X to form acids like Carbonic acid, Nitric acid and Sulphuric acid. Addition to this, study area is in close vicinity and surrounded by two Industrial Estate, Madkai and Kundai Industrial Estate in South West direction and North West directions. Both within radius of 10 Km, providing a possibility for acid rain in the vicinity (Singh and Agrawal 2007; Camuffo et al. 1988; Likens et al. 1972; Zhao et al. 2009). Photosynthesis, respiration and decomposition are also contributing to pH, decomposition activity rate is high in humid and sunny days leads to more production of CO_2, resulting in higher soil CO_2, forming carbonic acid, leads to lower pH or also another reason could be because of the interaction with the surrounding rocks. Test method used here is IS 3025 Part 11.

Colour, Odour, Turbidity, Hardness, TDS, Chloride, Calcium, Magnesium, Sulphates and Nitrates, all are observed under prescribed limits. Temperature recorded of spring water was 27°C, whereas outside temperature was 27.5°C. Iron, Alkalinity and Flourides were not detected. No detection of alkalinity means, the water's natural tendency to neutralize the acid itself is absent and this could be one of those reasons for low pH or acidic nature of spring water. Total Alkalinity as $CaCO_3$ analysed under chemical parameter and test method followed here is IS 3025 Part 23. Conductivity observed 33.60 µs/ cm under the test method of IS 3025 Part 14.

As per test method IS 3025 Part 38, Dissolved oxygen was analysed and observed value is 6.90 mg/Lt., test comes under organic demand. This parameter is almost at the lower edge. Ground water is generally consider to be with low DO, as exposure to air here is nearly absent. However, it can also mean that, the possibility of decomposition underground could be high, resulting high BOD, meaning more oxygen could have used for decomposition resulting in reduction of DO. More decomposition could also be the supporting hand for water to be more acidic in nature due to production of CO_2 as discussed before.

As per the test method IS 1622:1981 (Reaffirmed 2014), First bacterial parameter analysed is Total Coliform, in the bacterial observation, Total Coliform has observed with 23 MPN of Coliform organism (MPN/100ml). The presence of coliform indicates that the water is contaminated and usage for drinking and domestic purpose is not safe (Gyles 2007). The detection of Total Coliform could be because of the heavy rainfall occurred in the last two weeks of May 2021 during the Cyclone "Tauktae" and in the initial week of June (Pandya et al. 2020). After that the next two weeks were Sunny, with high humidity. May be because of this favourable condition for microbial activity like decomposition, leads to bacterial growth, because of this there is the possibility of increase in the total coliform numbers. Temperature and humidity plays a very important role in the growth and survival of microorganism, decomposition rate is higher in such conditions. Because of this, higher amount of total coliform bacteria must have travelled from soil to groundwater and spring water might have contaminated. Due to bacterial degradation of water, quality often leads to high incidence of waterborne diseases like Diarrhea and Cholera. Although, total coliform was present and contaminated the water, but E- Coli, i.e. second bacterial parameter analysed was absent. Indicating that, this bacterial parameter is under prescribed limits, but water is not safe for drinking as discussed before. Test method followed here is IS 15185:2016 (Reaffirmed 2018). In Physical parameter, the volumetric flow rate recorded was 28.14 Lt/min. Time taken to fill 20 Lt of bucket is 42.64 sec. It was observed that flow rate varies as per season and months. During the rainy season it overflows from opening vent, at very high flow rate and slowly keeps on decreasing gradually from June to May. In the month of May, flow rate reduces, but it does not go dry completely. Volumetric flow rate tells us about how much amount of water is discharged from the opening vent. Analysis indicates that the water is contaminated.

4. CONCLUSION

Assessment of quality of spring water has accomplished. Study shows that two parameters were beyond prescribed limits of drinking water standards, set by Indian standard drinking water and WHO. Major matter of concern is low pH (acidic nature) and presence of coliform makes water unfit for drinking purpose. When Information had received from locals that, the said spring water is good for health and has some medicinal properties, but according to observations, it indicates towards unsafety of spring water to drink, and it shows that either people were unaware of water quality or people has considered this water is safe, as it is a source of natural spring and sacred water.

This type of polluted water resources creates water scarcity and puts limitations on its uses, impacting optimum utilization of water resources that also in such area, where people are mostly depend on such spring water, where water supply from government or PWD is not regular and unreliable especially during summer season. Drinking this contaminated water will give an open invitation to serious illness and diseases. However, it can be useful for drinking and domestic purpose, but only after prior essential treatment at point source. Moreover, frequent testing and monitoring is suggested in future, monthly or on seasonal basis. Further analysis may lead to, more detailed illustration of its quality. Despite of good efforts taken by the Temple administration and villagers to maintain the quality and cleanliness, but that was not sufficient. Therefore, it is recommended to take more stringent and essential measures, to maintain the region, specially the watershed area to regain and retain the water quality and to avoid further degradation of water quality in future. Finally, analysis shows that spring water is of degraded quality in order to consume.

5. REFERENCES

Anyanwu, B.O., Ezejiofor, A.N., Igweze, Z.N. and Orisakwe, O.E. (2018). "Heavy metal mixture exposure and effects in developing nations: an update." *Toxics*, 6(4), 65.

Breda, Z. and Costa, C. (2013). "Tourism development, conflicts and sustainability: The case of Goa." *In Handbook of tourism economics:* Analysis, new applications and case studies (pp. 683-704).

Bui, Y., Lodhi, M. S. and Regional, N. E. (2020). "Assessment of spring water quality using water quality index method: study from upper Subansiri district, Arunachal Pradesh, India." *Int J Environ Sci,* 9, 898-908.

Camuffo, D., Bernardi, A. and Zanetti, M. (1988). "Analysis of the real-time measurement of the pH of rainfall at Padova, Italy: seasonal variation and meteorological aspects." *Science of the total environment*, 71(2), 187-200.

Chauhan, J.S., Badwal, T. and Badola, N. (2020). "Assessment of potability of spring water and its health implication in a hilly village of Uttarakhand, India." *Applied Water Science*, 10(2), 1-10.

Fromm, P.O. (1980). "A review of some physiological and toxicological responses of freshwater fish to acid stress." *Environmental Biology of fishes*, 5(1), 79-93.

Gyles, C.L. (2007). "Shiga toxin-producing Escherichia coli: an overview." *Journal of animal science*, 85(suppl_13), E45-E62.

Hem, J.D. (1985). "Study and interpretation of the chemical characteristics of natural water." Department of the Interior, *US Geological Survey.* Vol. 2254.

IS 10500, BIS. (2012). "Indian standard drinking water–specification (second revision)." *Bureau of Indian Standards*, New Delhi.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B. and Beeregowda, K.N. (2014). "Toxicity, mechanism and health effects of some heavy metals." *Interdisciplinary toxicology,* 7(2), 60.

Jan, A.T., Azam, M., Siddiqui, K., Ali, A., Choi, I. and Haq, Q.M.R. (2015). "Heavy metals and human health: mechanistic insight into toxicity and counter defense system of antioxidants." *International journal of molecular sciences,* 16(12), 29592-29630.

Jellyman, P.G. and Harding, J.S. (2014). "Variable survival across low pH gradients in freshwater fish species." *Journal of Fish Biology*, 85(5), 1746-1752.

Król, A., Mizerna, K. and Bożym, M. (2020). "An assessment of pH-dependent release and mobility of heavy metals from metallurgical slag." *Journal of hazardous materials*, 384, 121502.

Leivestad, H. and Muniz, I.P. (1976). "Fish kill at low pH in a Norwegian river." *Nature,* 259(5542), 391-392.

Likens, G.E., Bormann, F.H. and Johnson, N.M. (1972). "Acid rain." *Environment: Science and Policy for Sustainable Development,* 14(2), 33-40.

Metri, S. M. and Singh, K. (2010). "Study of rainfall features over Goa state during southwest monsoon season." *Mausam*, 61(2), 155-162.

N. Goa (2011). "Goa District Census Handbook Census of India 2011."

Pandya, U., Khandelval, S., Sanghvi, H., Joshi, E., Vekaria, G.L., Jaaffrey, S.N.A. and Soni, M. (2021). "Cyclone 'Tauktae'-Observed Through Data & Satellite Images." *IRJMETS Publication*-2021.

Patil, V.T. and Patil, P.R. (2010). "Physicochemical Analysis of Selected Groundwater Samples of Amalner Town in Jalgaon District, Maharashtra, India." *E-Journal of Chemistry,* 7(1), 111-116.

Potdar, S.S., Kulkarni, S., Patil, P., Pawar, R.P., Jakhalekar, V.V. and Nade, D.P. (2019). "The long-term trend analysis of rainfall data from 1901 to 2015 for Maharashtra and Goa region from India." *International Journal of Water*, 13(3), 293-309.

Rose, S. and Long, A. (1988). "Monitoring dissolved oxygen in ground water: some basic considerations." *Groundwater Monitoring & Remediation,* 8(1), 93-97.

Saria, L., Shimaoka, T. and Miyawaki, K. (2006). "Leaching of heavy metals in acid mine drainage." *Waste Management & Research,* 24(2), 134-140.

Singh, A. and Agrawal, M. (2007). "Acid rain and its ecological consequences." *Journal of Environmental Biology*, 29(1), 15.

Standard, I. (2006). "Methods of sampling and test (physical and chemical) for water and wastewater." *IS. Search in. Veling.* 15º 25' 59" N and 73º 58' 20" E Google Earth. June 30, 2021.

World Health Organization. (1963). "International standards for drinking-water."

Zhao, J., Wang, C., Jin, Z., Sun, G. and Xiao, J. (2009). "Seasonal variation in nature and chemical compositions of spring water in Cuihua Mountain, Shaanxi Province, central China." *Environmental geology,* 57(8), 1753-1760.

Advancements in Water Auditing Towards Improving Service Efficiency of Water Supply Systems

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Abstract: *As fresh water becomes increasingly scarce, water resource management and sustainability will be vital to maintaining quality of life and economic development in communities around the world. The world is facing chronic water risks with the demand-supply gap increasing at an alarming pace. The industry is an important stakeholder in water resource management and as a responsible member of the community, needs to be proactive in combating water risks. Water audits act as an instrument to identify areas of higher specific water use, assess wastewater pollutant load and determine techniques for mitigation through the application of 3R (Reduce, Reuse, and Recycle) principle.*

Key Words: *specific water use, assess wastewater pollutant load, sustainable water management solutions, identifying opportunities to improve water use efficiency, water mapping and comprehensive water balances.*

1. INTRODUCTION: WATER AUDIT PROCESS

Water-audit is used for reducing water-losses, leakages and gives the information of water used by consumers. The water audits follow a multi-staged approach in order to provide both short-term and long-term sustainable water management solutions. Water Audit is a systematic process of objectively obtaining a water balance by measuring the flow of water from the site of water withdrawal or treatment through the water distribution system and into areas where it is used and finally discharged. Similar to energy audit, water audit is a method to quantify the sources of water being used in the enterprise, thereby understanding the current state of water consumption, minimizing losses, and identifying opportunities to improve water use efficiency (D.P. Bhattarai and N. M. Shakya 2019).

The various steps followed during the course of a detailed water audit are as follows:

- A Preliminary Water Survey (PWS)/reconnaissance surveys conducted before initiating the detailed water audit (DWA). This helps in identifying specific areas to be included in scope of work.
- The detailed water audit agreement to efficiently meet client needs, schedules, and defined scope.
- A last mile discipline approach is followed.
- State of the art instruments and portable water quality testing kits are used for measurement and monitoring.
- Water mapping and comprehensive water balances.
- Water quality assessments.
- Recommendations and identification of strategies.
- Training programs organized for sensitizing the plant personnel, operators and employees raising awareness.

2. WATER RESOURCES MANAGEMENT PERFORMANCE AUDIT OBJECTIVES

The goals of a performance audit of water resources management may be broken down into the following categories:

2.1 Authenticity

If the data and materials under evaluation are not genuine, then all of the audit findings acquired will be incorrect and have no significance whatsoever. Therefore, guaranteeing the validity of data and materials is a precondition for auditing to take place.

2.2 Legality

A succession of government documentation, such as appropriate rules and regulations, must be followed in order for all water resources management efforts to be successful.

2.3 Economical

Economic objectives are concerned with whether water resources management is consistent with the notion of conservation and if funds are being used in a scientifically sound manner. In the process of water resources management, not only must the quality be met, but it must also be ensured that the investment costs are kept to a bare minimum.

2.4 Efficiency

The most important aspect of efficiency is the ability to do the most useful work at the lowest possible cost. Evaluation of water resource auditing efficiency is mostly dependent on investment and return, including whether or not the investment generates a high-quality return, among other factors.

2.5 Effectiveness

The effectiveness of water resources relates to whether or not the performance audit of water resources is up to the standards, whether or not the intended outcomes are obtained, and whether or not the water resources are effective once they have been managed and administered.

3. MEASURING EQUIPMENT USED IN WATER AUDIT

Depending on the complexity/variety of production type, measuring equipment for a water audit include- Water meter, Water ruler, Water can, Water pressure meter, Water flow meter, Calculating tools, TDS, etc.

Fig.1. *Electrical conductivity meter, TDS (total dissolved solid), PH*

Fig. 2. *Online water flow meter*

A Water audit determines the amount of the water lost from the distribution system due to leakage and other reasons and the cost of this loss to the utility. Comprehensive water audit can give a detailed profile of the distribution system and water users, thereby facilitating easier and effective management of resources and improved reliability. It is an important step towards the water conservation and linked with the leak detection mechanism, can affect saving of a significant amount of money and time. It can serve the purpose of correct diagnosis of the problem faced in order to suggest optimum solution. It may also prove an effective tool for realistic understanding and assessment of present performance level and efficiency of the service and the system for the future expansion, rectification of faults or modernization (Choudhary et al. 2021)

Element of the water audit includes:-

1. Record of the amount of the water produced / received
2. Record of the amount of the water delivered to metered users
3. Record of the amount of the water delivered to unmetered users
4. Record of the amount of the water loss
5. Measures to address water loss (through leakages and other an unaccounted water losses)

4. FIVE F ORCES DRIVING THE FUTURE OF WATER

American Water Works Association (AWWA) has identified five critical drivers that will influence progress toward a sustainable and resilient water future: sustainability, technology, economics, governance and social/demographic. These drivers will be considered by the Water 2050 think tanks and shape all future work supported by this initiative.

4.1 Sustainability

Managing our planet's limited water resources and built infrastructure for water is paramount. Climate change is among the biggest risks. It will bring conditions that are more fierce and less predictable: extended droughts and heatwaves, increased hurricanes and wildfires, and severe winter storms. The future will require skillful and creative stewardship of our most vital natural resource, as well as innovative approaches to keep water infrastructure strong and resilient.

4.2 Technology

As the world enters the fourth industrial revolution, water professionals have access to new technologies that are changing the way they interact with water resources, water systems and the people they serve. Advances in data, analytics, the Internet of Things (IoT), machine learning and artificial intelligence will increasingly empower consumers and influence water system operations. Adoption of new technologies will solve complex problems and sometimes introduce unintended challenges.

4.3 Economics

Water is a critical economic engine for North American communities and across the globe. Increasingly, the water community is asked to do more with less, while also addressing rising infrastructure needs. We must consider important economic factors such as regionalization, supply chain resilience, decentralized treatment, ESG approaches to assessing risks and value, and the benefits of a circular economy. Rate-setting will occur in a world more keenly aware of equity and affordability challenges.

4.4 Governance

The roles of federal, provincial, state and local governments significantly impact how water utilities are operated and regulated. Both economics and governance will shape the model of tomorrow's water utilities. Some communities may turn to regional solutions to gain efficiencies. As regulatory structures evolve, communities will have to evaluate new approaches, such as fit-for-purpose standards and decentralized treatment.

4.5 Social and Demographic

Public interest and concern about water quality and equity is rising, which means all communities must work to strengthen public trust. Simultaneously, potential population shifts between urban and rural areas are creating resource and infrastructure challenges — while also forcing community-driven water solutions. Population growth in water-stressed communities will require innovative thinking to manage limited supplies.

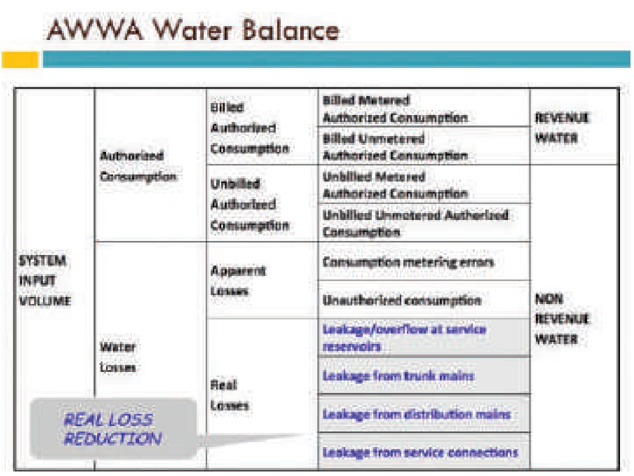

Fig. 3. *AWWA water balance*

Banks prepare statements of debits and credits for their customers as well as provide a report of money going into and out of accounts, just like any other business. The water audit shows how much water is flowing into and out of the distribution system, as well as how much water flows to the consumer. The International Water Association (IWA)/American Water Work Association (AWWA) has undertaken a large-scale initiative to mitigate the above listed issue with the aid of auditing. In other words, water deficit is the difference between total output and total consumption. Auditing of water is a comprehensive and scientific study of project water records. It includes auditing of the domestic sector, industrial sector, agriculture sector and other sectors in which water is used.

5. THE GOVERNMENT OF MAHARASHTRA HAD INITIATED "SUJAL NIRMAL ABHIYAN" PROJECT

The Government of Maharashtra had initiated "Sujal Nirmal Abhiyan" project under which many ULB participated. Shrivardhan Municipal Council also participated in various work fields of water supply like Water Audit, Energy Audit, providing and Installing Flow Meter. Data gathered from field measurements in 38 Maharashtra towns. Authorized consumption (revenue water) is 1.572 million liters per day (MLD) (54%) and water losses (apparent losses and real losses) is 1.357 MLD (46%). 15% losses in transmission are also considered. So, immediate and long-term improvement is needed in system components like head work, raw water gravity main from intake to Arethi sump and pump house and others.

Probably, the water network is developing in response to the rising need of the community it represents. Surface water will be exploited first. Leakages should be reduced from the water distribution system. PALM (Pump and Leakage Management) project is targeted to decrease leakage from every water distribution network. A noise is caused by a leak in a pressurized system, the operating principle of acoustic instrument which show the location of leakage. Hydraulic modeling also used for leak detection from water distribution system, in this method does not require any transducer, portable flow meter and other instrument, only monitor pressure reduction in distribution system (Ansink et al. 2021).

Avoid water wastage, electricity usage and conveniently prevent water for our future generation by using a water monitoring system. By using a tank water level monitoring system to stop the overflow of water, water pollution monitoring system is used to detect the pollution in water and leak detection monitoring is used to find the location of leak in the distribution system. In water level monitoring, LED, sensors and microcontroller. In water pollution monitoring, pH, turbidity and temperature are monitored. An acoustic leak detector is employed in a leak detection system; when a leak is discovered, an ultrasonic signal is generated, which is signaled by an increment in the LED meter and a rushing sound in the headset. By using wireless sensor networks, the concept of smart offices/homes is completed.

6. IN NAPA, CALIFORNIA SPRINKLER TIMES ONLINE PROGRAM CREATING A CUSTOMIZED SPRINKLER WATERING SCHEDULE

Sprinkler Times is an online program and tablet and smart phone app that creates a customized sprinkler watering schedule to conserve water. It was developed by Tom Del Conte and Logan Oates, the water manager at Del Conte Landscaping in Fremont, California. In addition to the landscaping company, Del Conte owns Vision Recycling, a composting and mulch production facility. Sprinkler Times includes its water-wise home survey, a free service to help single- and multifamily residential customers use their water more efficiently and reduce their bills. A water conservation representative visits the homes and evaluates water usage, including toilet flush volumes and faucet and showerhead rates, and provides free high-efficiency replacement fixtures if warranted. The representative will also inspect a home's irrigation system and help with irrigation scheduling. They will also offer to assist the customer with Sprinkler Times data input and programming the resulting irrigation schedule into their controller.

A significant benefit of the program is that it tailors the water schedule to the lawn's ability to actually absorb the water being applied. The software has an adjustment feature if the irrigation is under- or over-applying water Lipiwattanakarn et al. 2021).

Fig. 4. *Sprinkler Times program of sprinkler*

Sprinkler Times also emails a notice each month to homeowners to remind them to adjust the watering rates. In April and May, watering rates are moderate, and then they kick up in June and especially July, But it is in August, September and October where most of the water is wasted. The amount of solar radiation dictates the plant's watering needs, so as the days get shorter, the application rate should get tweaked downward. Sprinkler Times prompts homeowners to make the appropriate seasonal adjustments. A traditional home or commercial landscape water audit develops a base watering schedule. It typically starts by setting out "catch cans" (cylinders with measured throat openings to catch the water) to measure the output per hour of the watering system, as well as the uniformity of coverage from the sprinkler heads. That typically yields another 25 to 40 percent in water savings.

Fig. 5. *Landscaping in Fremont, California*

7. IIT TIRUPATI AND GW&WA GOVERNMENT OF ANDHRA PRADESH MOU FOR SHARING OF REAL-TIME GROUNDWATER MONITORING WELLS DATA

IIT Tirupati (IITT) entered into an MoU with Ground Water & Water Audit (GW&WA) Department, Government of Andhra Pradesh to promote interaction between GW&WA Department and IIT Tirupati in mutually beneficial areas of ground water resources assessment and sustainability and to enhance research and development interests between the two organizations. The proposed modes of collaboration include sharing of real-time groundwater monitoring wells data, training of GW&WA Department employees by IIT Tirupati, sponsoring of R&D projects and eligible employees of R&B Department for pursuing M.S./M. Tech./Ph.D. degrees at IIT Tirupati. The major focus of collaborative efforts will be on evaluating and developing techniques for ground water sustainability in the face of increased demand for agricultural water and climate change.

8. NOVEL INITIATIVES OF WATER AUDIT

8.1 University of Nebraska-Lincoln uses Innovative Technologies to Optimize Nitrogen Fertilizer use

Researchers at University of Nebraska-Lincoln are working with farmers on Project SENSE (Sensors for Efficient Nitrogen Use and Stewardship of the Environment), which uses innovative technologies to optimize nitrogen fertilizer use. As part of the project, crop canopy sensors are used to measure the real-time nitrogen status of crops. This information is then used to produce nitrogen application rate recommendations that can ultimately lead to greater crop productivity, decreased fertilizer use, and improved water quality as a result of reduced fertilizer runoff. (Ahmad et al. 2019)

8.2 Colorado River Municipal District's Big Spring Facility using Direct Potable Reuse (DPR) Processes

The communities of Big Spring and Wichita Falls, Texas, built the country's first two potable reuse facilities, using multiple barrier technologies and intense monitoring. Presently, Colorado River Municipal District's Big Spring facility provides water to five communities using direct potable reuse (DPR) processes. Wichita Falls implemented an emergency DPR system in response to severe drought in 2014. When drought conditions subsided, the DPR system was decommissioned and Wichita Falls subsequently implemented a permanent indirect potable reuse (IDR) system.

8.3 Algae-Based Wastewater Treatment @ Indiana Department of Natural Resources

The Indiana Department of Natural Resources worked with Commonwealth Engineers, Inc. and One Water Group to install algae-based wastewater treatment systems at two of its state parks. Both locations use an algaewheel® system, which works similarly to a rotating biological contactor. Wastewater is conveyed to a basin containing partially submerged paddles (wheels), which are rotated via a blower. Biofilm, made of a consortium of algae and bacteria, attached to the wheels supply oxygen to the wastewater while removing nutrients. These small, decentralized systems are ideal for low flow facilities. Little land space is required and the system is capable of handling variable flows with changes in seasonal demands (Mathew et al. 2021).

8.4 Improving Resiliency of Water Infrastructure to the Impacts of Climate Change

Due to damage from Hurricane Ivan in 2004, Florida's Emerald Coast Utilities Authority had to relocate Main Street Wastewater Treatment Plant away from the coastal plain and rebuilt. The new Central Water Reclamation Facility has treatment technology that enables the reuse of 100 percent of the nearly 22.5 million gallons per day (average flow) treated at the facility. Additionally, the new plant was built to withstand Category Five hurricanes and now stands 50 feet above sea level, thereby increasing resilience to sea level rise and flood risk (Yuhui Wang 2022).

8.5 Managing Stormwater with Intensely Implemented Green Infrastructure

Green City, Clean Waters is the city of Philadelphia's 25-year plan to protect and enhance its watersheds by managing stormwater with intensely implemented green infrastructure. Recently, Philadelphia celebrated an impressive landmark in the program; 1,000 acres throughout the city have been greened, and counting. Save the Rain is Onondaga County's and the city of Syracuse's visionary stormwater management and public outreach program, featuring over 200 projects, capturing over 120 million gallons of runoff each year to protect their watershed. Every project advanced through the program has a unique Web page where the public can review the project design elements, cost, and stormwater capture objectives.

8.6 Real-Time Monitoring Technologies on the Hudson River

The Hudson River Environmental Conditions Observing System (HRECOS) is a network of real-time monitoring stations on the Hudson River Estuary. HRECOS is a collaborative effort between multiple agencies, including the New York State Department of Environmental Conservation, USGS and NOAA, among others. The River and Estuary Observatory Network is an effort between Clarkson University's Beacon Institute for Rivers and Estuaries and IBM to use real-time monitoring technologies to better understand the Hudson River ecosystem from the headwaters in the Adirondack Mountains to the ocean (Xu et al. 2021).

9. CONCLUSIONS

With water availability becoming scarce due to multiple reasons, time has come to enforce audit of water supplied regularly to reduce the losses in the distribution system. There are two types of losses, real and apparent losses. Real loss includes water lost through leakages in distribution systems, service connections and storage tanks (including overflow). Apparent loss includes meter and record inaccuracies and unauthorized water uses such as theft and unauthorized connections. In order to improve the efficiency of the water supply systems, States are to regularly take up water audit of identified systems for effective improvement. In order to ensure that the investments made under the Jal Jeevan Mission lasts on long-term basis, it is important to prepare the water budget of the village by assessing the total available water from all sources both ground and surface levels. Environmental degradation and contamination of water resources have become more prominent, necessitating the inclusion of environmental performance audits in audit work.

10. REFERENCES

Ansink, Erik and Ornaghi, Carmine and Tonin, Mirco, Technology vs information to promote conservation: Evidence from water audits (February 5, 2021). Tinbergen Institute Discussion Paper 2021-014/VIII. http://dx.doi.org/10.2139/ssrn.3779801

Choudhary S, Dohare D, Bajpai S. Review on Conservation of Water by Water Audit. Curr World Environ 2021;16(3). DOI:http://dx.doi.org/10.12944/CWE.16.3.4

D. P. Bhattarai and N. M. Shakya, "Conjunctive use of water resources in sustainable development of agriculture in t," *Journal of the Institute of Engineering*, vol. 15, no. 2, pp. 210–217, 2019.

M. Mathew, S. George, R. Menon, and J. Tharakan, "City scale water audit of a pilgrimage town in South India," *International Journal of Water Resources and Environmental Engineering*, vol. 13, no. 1, pp. 88–96, 2021.

S. Lipiwattanakarn, S. Kaewsang, C. Makpiboon, and J. A. Changklom, "Water quality audit in drinking water distribution networks," *Journal of Water Resources Planning and Management*, vol. 147, no. 3, Article ID 04020113, 2021.

Yuhui Wang, "The Study Based on Intelligent Big Data Technology for Water Resources Audit", Scientific Programming, vol. 2022, Article ID 1188402, 9 pages, 2022. https://doi.org/10.1155/2022/1188402

W. Xu, Z. Zhong, D. Proverbs, and S. Y. Xiong, "Enhancing the resilience of the management of water resources in the agricultural supply chain," *Water*, vol. 13, no. 12, 1619 pages, 2021

Z. Ahmad Fuad, S. Eddy H., Y. Badronnisa, I. Syazwani. Water leak detection method in water distribution network. IOP Conference Series- Earth and Environmental Science; 2019. https://iopscience.iop.org/article/10.1088/1755-1315/357/1/012033/pdf

Extensive Review of Water Resources Management Using WEAP and Its Integrated Models

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Abstract: *Sustainable development is most focused in present times in which water management and conservation play a vital role. Water scarcity is one of the alarming problems in today's world and so water allocation and its conscious use is the area of interest for many researchers in the field. This problem can be addressed by proper planning and design and this will be a multidisciplinary approach and needs to be evaluated deeply. For this purpose, Water Evaluation and Planning (WEAP) software is used and with the use of this, different models for water management can be made and evaluated easily. In this paper, different WEAP models are reviewed and an overview of their outcomes is presented. WEAP has a wide application area which ranges from irrigation to water quality to ground water assessment and even the integration of the WEAP model with different models was used for forecasting the impact of climate change on the management of water resources. For irrigation purposes, the WEAP-MABIA method with dual crop coefficient is under research and still under exploration which has good potential in the future for research. This paper has deeply evaluated all the applications of WEAP and explored the areas where WEAP has good potential in managing water resources. Overall, WEAP is one of the most valuable tools and can play an important role in the decision-making process for managing water resources and can help predict the future water crisis and help in proper planning for the same.*

Key Words: *WEAP, Water allocation, Groundwater, Climate change, Dual Crop Coefficient, Water Resource Management, Evapotranspiration.*

1. INTRODUCTION

Water is the principal element for the existence of life on the planet. Water is needed for the survival of living beings, agriculture, and even industries consume a considerable amount of water for different industrial processes. With the increasing population, demand for the water raises directly as well as indirectly. Water needed by humans for their existence like drinking and sanitation can be referred to as a direct increase in the demand of water. With an increasing population, the demand for food increases which will increase agriculture and the consumption of water in agricultural processes increases and this can be referred to as an indirect increase in the demand of water. Even in industries, there is an increase in the demand of water because the production increases and will naturally tend to increase the use of the resources and water and this is another indirect source of increase in the water demand.

As mentioned in the above paragraphs, there is a strong need to identify and plan the proper allocation and use of water resources to efficiently deal with the water scarcity problem. For this purpose, different hydrological models have been developed that correlate different parameters and allow to study of the relationship between climate and water resources. These hydrological models are then integrated with the socioeconomic factors and useful results are (Nivesh & Kumar 2018; Salman et al. 2021; Skoulikaris & Zafirakou 2019). For example, there are several models developed by different researchers which include the soil and water assessment tool (SWAT) watershed model, spatial agro-hydrological salinity model (SAHYSMOD) (Boufala et al. 2022; Goyal et al. 2018; Peng et al. 2020; Sharafati et al. 2020). Other models which are studied are the agro-hydrological land surface process model (PROMET) (Degife et al. 2021). Some models based on artificial intelligence are also studied by different researchers on different parameters parameters (Malik et al. 2020; Nivesh et al. 2022). The most widely studied model in different basins of the world is done using the software known as Water Evaluation and Planning (WEAP) (Moncada et al. 2021; Ougougdal et al. 2020; Yao et al. 2021; Yates et al. 2005). From the above-described different models, WEAP has found its prominence in water resource allocation in various socio-economic and climate conditions.

Evapotranspiration is a factor that predicts agricultural water demand, which is influenced by weather conditions and water schedules. It is the combination of evaporation from the land surface and transpiration from crop tissues. Most available models for water demand use non-spatial point data of reference evapotranspiration and crop coefficient values from literature. The crop coefficient is an important parameter for irrigation scheduling and water allocation, but its empirical values can cause significant error in estimating crop water requirement. (Allen et al. 1998; Doorenbos 1977; Jagtap & Jones 1989).

It is also noted that the use of remote sensing technology based on vegetation indices was used to determine the crop water requirements (Gontia & Tiwari 2010; Ray & Dadhwal 2001; Reginato et al. 1985; Roerink et al. 1997). By using the crop coefficients based on basal and canopy reflectance, daily crop evapotranspiration was estimated (Jayanthi et al. 2007).

2. BRIEF OVERVIEW OF WEAP

The water Evaluation and Planning (WEAP) model of the Stockholm Environment Institute came into existence in 1988. WEAP operates on the basic principle of water balance accounting by equating water use patterns, equipment efficiencies, reuse, and allocation with supply side like reservoirs, groundwater, and stream flow. WEAP model has extensive use in water resource management in rainfed and drought-prone areas. The first use of the WEAP model in 1992 was to study the Aral Sea (Raskina et al. 1992). There is continuous development in the WEAP model since into came into use. The latest model WEAP21 has introduced a modern Graphics User Interface and advanced algorithms which have addressed the complex problem of water resource allocation. For hydrological modelling WEAP21 provides an advanced platform that has integrated conceptual rain runoff, alluvial groundwater model, and stream water quality in one platform. Simulation of future scenarios about climate change, yield, population and technology, and other socio-economic parameters were analysed using WEAP in the integration of different models for major agriculture-dominated regions in Hungary, Argentina, Brazil, China, Romania, and the U.S. (Rosenzweig et al. 2004)

WEAP was used to simulate the impact of a different-sized reservoir in the Upper Volta in Ghana (Hagan 2007) WEAP was also used as a water management support system for the Amman Zarqa basin in Jordan's optimistic scenarios and advanced wastewater treatments (Al-Omari et al. 2009). Olifants catchment in South Africa was also modelled using WEAP (Arranz et al. 2007) In all the analyses for water demand analysis and prediction, this WEAP model gave a satisfactory result. WEAP model has a broad canvas for applications ranging from agriculture and municipal systems to single catchments or complex transboundary river systems.

3. DIFFERENT APPLICATIONS AREAS OF WEAP

The application area for the WEAP model is very wide. There are different conditions and different models available in the WEAP which can help in studying many different water management problems. The application of WEAP is profoundly seen in hydrological studies, climate change, and irrigation management, groundwater modelling, and modelling for water quality management. Research and studies in each of the applications are reviewed and elaborated here below in the proceeding sections.

3.1 Application of WEAP for Irrigation Management

The use of the WEAP model can be particularly impactful in agriculture, especially when it comes to managing irrigation. In a study conducted in the semi-arid region of Vadodara district on the Sardar Sarovar Project, the WEAP model was used to optimize water use efficiency and increase crop yields in an irrigation deficit area, specifically for the cotton crop. The researchers explored five different scenarios for irrigation water stress, ranging from conventional irrigation to deficit irrigation and no stress irrigation during the vegetative phase or throughout the entire growth period. The results indicated that the no stress allowance scenario, with the highest irrigation amount of 307 mm, resulted in increased crop yield without any significant deviation in water usage efficiency (Bhatti Gopal & Patel H.M. 2015).

In Chaj-Daob, the Indus basin irrigation system of Pakistan WEAP model with six different scenarios was used to analyse the demand and supply of surface water to the crop. In outcomes, it was noted that the Lower Jhelum Canal command area was more sensitive to water scarcity as compared to the Upper Jhelum Canal. In this study, it was concluded that with the irrigation efficiency improvement by lining the canal, reducing, and replacing the high delta crop with low delta crop was sufficient to reduce the canal water deficit and will optimize the canal water allocation. The cropping area and irrigation system should be improved to further optimize canal water management (Ahmed et al. 2021)

WEAP model was also used for identifying the proper crop pattern and irrigation scheduling and canal water allocation based on evapotranspiration. The command area was the Hakra 4R canal in Pakistan. Generally, the season for a cotton crop is for 195 days which starts from May and extends till the month of November, and for Wheat, it is for 171 days which starts from November and extends till the month of May. The difference in the potential and actual evapotranspiration is higher in the month of August and September for cotton and for wheat it is higher in the month of March and April. Canals are not running during the month of December and January and this is the time when there is wheat crop sown, so here the water should only be pumped in this canal whenever required as this is the time for the highest evapotranspiration (Ahmed et al. 2015).

In Brunei, Darussalam, a study was conducted on a special rice variety (MRQ76) over three different growing seasons using the WEAP-MABIA model based on the soil-water balance approach. The objective of the study was to optimize irrigation schedules to ensure efficient water usage and high rice yields. To achieve this, evapotranspiration was estimated to assess water demand and irrigation requirements. The study explored four different irrigation scenarios and found that full irrigation without stress resulted in the highest yield. In a separate study in the command area of the Tandula River of Lohara Village in Chhattisgarh, crop water requirements were analysed to estimate water loss through evapotranspiration. The study used the WEAP-MABIA method to simulate the need for water under changing climate, soil, and crop conditions and to identify monthly crop water and irrigation requirements. The study found that changing the crop pattern and using advanced irrigation systems could improve yield with efficient water usage (Jabloun 2012; Husain & Rhyme 2021; Tikariha & Ahmad 2022).

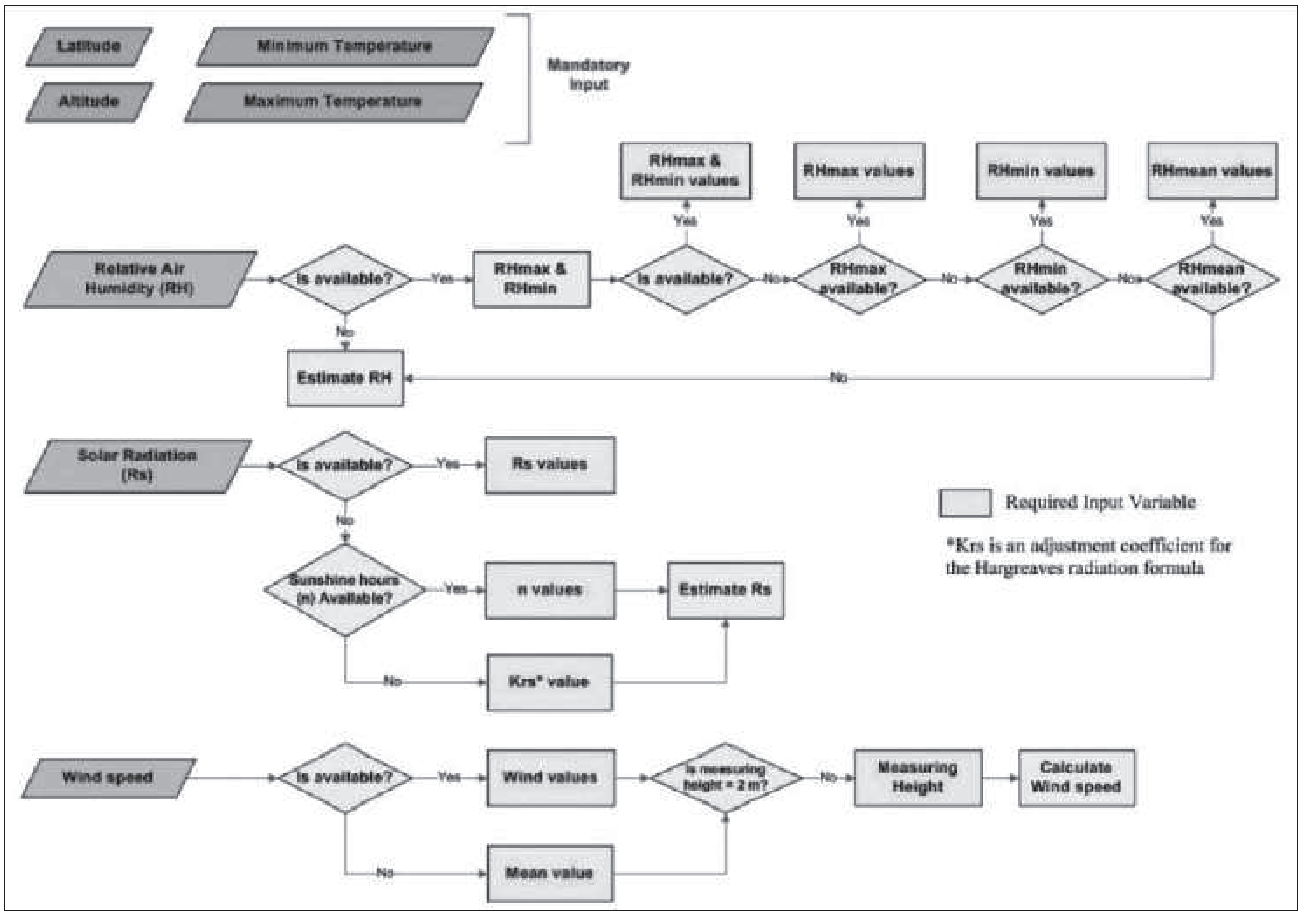

Fig. 1: *WEAP-MABIA Reference Evapotranspiration Calculation: Climatic data availability (Jabloun, 2012)*

In this study, the dual crop coefficient approach was used using WEAP and the results were compared with the single crop coefficient, and the same water requirements of the crop were also evaluated considering different soil textures. From the study results, it was noted that with the double crop coefficient approach, water requirements were increased except for tomato, eggplant, and broad bean crop. According to the soil textures, the requirement of the water for the crop was varying. For Wheat, it was 429mm and 433mm for sandy loam and clay loam with irrigation intervals of 11 and 12 respectively. For silt loam, the water requirement was 417mm with 8 irrigation intervals (Najm et al. 2020).

A study developed an Alternate Wetting and Drying (AWD) model for rice cultivation and used WEAP to assess water requirements for two locations. Results showed a 12-27% reduction in water requirement in the dry season and 34.3% overall. WEAP was also used to assess the impact of upstream and downstream water resources and revealed that the water level will decline substantially without intervention. The AWD scenario showed a 50% improvement in water availability, highlighting the usefulness of WEAP for water resource assessment (Schneider et al. 2019).

3.2 Application of WEAP for Climate Change

The impact of climate change on the Nebhana Dam system was assessed using the WEAP model. Projections from five GCMs under the emission scenarios of RCP4.5 and RCP8.5 were used for the period of 2021-2080. A decrease of 11.4% in rainfall and a reduction in inflow by 24% was noted, which could result in water scarcity. The WEAP model showed that water availability will decrease, and irrigation requirements for wheat and citrus trees will be affected. Proper water resource management is needed to cope with the projected water scarcity (Allani et al. 2020)

The WEAP model integrated with SWAT was used to assess the impact of climate change on hydrology and the demand-supply relationship for water. Three climate change scenarios were simulated, indicating a decrease in stream flow and water availability. The study suggests that the construction of a reservoir could mitigate the impact of climate change on irrigation water requirements. (Touch et al. 2020).

3.3 Application of WEAP for hydrological Assessment

The WEAP model was used to develop a water management strategy for the upper Indus basin, considering different climatic and socioeconomic variations. Five sub-basins' stream flow was calibrated and validated. Unmet water demand was computed for the projection period of 2006-2050, with different scenarios considering urbanization, population growth, and climate change. The results showed an estimated unmet water demand of 134 MCM, which could be reduced by building dams for sustainable water management (Amin et al. 2018).

The WEAP-MABIA method was used to develop an agricultural water demand model for the Ur River watershed in Madhya Pradesh. The method used a dual crop coefficient approach to independently calculate soil evaporation and transpiration. The model was calibrated using the PEST tool, and future water demands were projected considering climate changes. Results showed a higher unmet demand for agriculture usage due to domestic water supply prioritization. Efficient irrigation practices and rainwater harvesting were suggested as potential solutions. (Agarwal et al. 2019).

In the sub-basin of the Narmada River, demand/supply, recharge, and draft were predicted using the WEAP model. For this study WEAP model was a decision support system for managing the watershed. Four scenarios were developed which were High population growth, High Industrial Growth, rainwater harvesting, and water storage structures were implemented in the WEAP model. Results from the study revealed that to reduce unmet water demand for domestic and agricultural requirements, artificial groundwater recharge structures and storage structures should be developed (Carpenter & Choudhary 2022).

3.4 Some other Important Applications of WEAP

To analyse the reliability of the supply system in Iraq Nineveh Province, WEAP was used in couple with MODFLOW. In this study, the conceptual groundwater model was converted to the numerical model using MODFLOW and after calibrating the model, it was linked with the WEAP. It was observed that when groundwater was used as an extra resource to the surface water resource, substantial improvement was seen in the reliability of meeting the demand. To substitute for the future water shortage, groundwater can serve as a dependable resource. A major contribution of this research was to unify the surface water with groundwater and then use both sources alternatively whenever needed. The mechanism proposed here in this study is helpful in predicting future demand and supply relations and can help in getting prepared for the future water crisis (Alslevavni & Almohseen 2017).

A retrospective quantitative water management balance of surface water was conducted using WEAP for the Horn River basin for the projected period of 2010-2015. The study evaluated the functionality of WEAP in terms of its implementation, input data, and time required. Results showed that WEAP has a user-friendly GUI, provides good visuals for results, and has an integrated approach to solving water resource management problems without needing detailed inputs.

The study aiming for glacier-hydrological assessment in a small basin in western Himalaya and its impact on two small hydro-power projects in that basin was done using WEAP. The WEAP model was used for integrating cryosphere, hydrology, and hydropower production modelling by considering the climate variations in the 21st century. The five global climate models were used with RCP 4.5 and 8.5. This study revealed important insights related to climate-adaptive designs and planning for future hydropower projects in the Himalayas (Shirsat et al. 2021)

In high mountain catchments, climate variations have a significant impact on cryosphere and hydrology, affecting water resource availability. Data scarcity in these regions makes it difficult to develop process-based models, but water resource models like WEAP can provide a conceptual approach. Although WEAP has an inbuilt glacier module, some limitations like overlooking glacier area change and ice flow can lead to variations in results (Momblanch et al. 2022)

4. CONCLUSION

From the review of the work done in the area of water resource management using WEAP, the following important conclusions have been derived:-

1. WEAP can be used to build complex water resource management models and it includes demand priority and supply preference approaches for solving water allocation problems with the LP optimization algorithm.
2. WEAP is a decision support system in water resource management and can be helpful in strategy making and planning of water resources.
3. Application of WEAP in hydrological simulations can give good insights into the demand and supply and can help in designing the Demand Management Strategy. This application of WEAP helps in planning for the projected period and can help in proper planning of water resources to avoid issues related to the supply and demand of water resources in the forecasted time.
4. The application of WEAP in forecasting the climate impacts on water resources is a notable contribution and serves as an important tool for making strategies for water allocation and building a demand-supply model for the projected period.
5. The application of WEAP is not limited to the aforementioned areas, but it also plays an important role in irrigation water management. WEAP-MABIA method is used for estimating the crop water requirement and even the yield of the crop can be improved by proper allocation and scheduling of water in the agricultural field.
6. WEAP can also be used in conjunction with other models for climate change, water quality modeling, and groundwater modelling. Results and models of software like MODFLOW can be linked to WEAP and modelling for groundwater is done. For modelling water quality, WEAP is coupled with the software known as QUAL2K. A coupling of WEAP and SWAT (Soil and Water Assessment Tool) can be used to model the impact of climate change on the hydrological regime by predicting monthly and seasonal stream flow and a demand-supply relationship can be established.

However, WEAP appeared to be a useful tool with several applications, there are also limitations of WEAP which were observed while reviewing the work of different researchers. For groundwater modelling, WEAP only considers alluvial aquifers and it is not capable to model the sedimentary and fractured rock aquifers. While using WEAP for Strategic Environment Assessment, where different scenarios were developed to understand the impact of different activities on local water resources, difficulty was encountered in developing a scenario for mitigation of proposed activities in the local water resource system which led to finding a solution outside the assessed scenario.

5. MAJOR FINDINGS AND FUTURE

After reviewing the different applications and researches where WEAP was implemented, it is observed that there is more opportunity in irrigation and agriculture water planning. Parameter Estimation Tool (PEST) can be used for calibrating the model and this is inbuilt into WEAP itself. WEAP can serve as a very important tool and can give very good water allocation and scheduling strategies for agricultural purposes. WEAP-MABIA method with dual crop coefficient is less explored yet and still more work in the same area using this method can reveal good results.

6. REFERENCES

Agarwal, S., Patil, J. P., Goyal, V. C., & Singh, A. (2019). Assessment of Water Supply–Demand Using Water Evaluation and Planning (WEAP) Model for Ur River Watershed, Madhya Pradesh, India. Journal of the Institution of Engineers (India): Series A, 100(1), 21–32. https://doi.org/10.1007/s40030-018-0329-0

Ahmed, N., Lü, H., Ahmed, S., Nabi, G., Wajid, M. A., Shakoor, A., & Farid, H. U. (2021). Irrigation supply and demand, land use/cover change and future projections of climate, in Indus basin irrigation system, Pakistan. Sustainability (Switzerland), 13(16). https://doi.org/10.3390/su13168695

Ahmed, N., Mahmood, S., & Munir, S. (2015). Estimation of potential and actual crop evapotranspiration using weap model. Sci.Int. (Lahore), 27(5), 4373–4377.

Allani, M., Mezzi, R., Zouabi, A., Béji, R., Joumade-Mansouri, F., Hamza, M. E., & Sahli, A. (2020). Impact of future climate change on water supply and irrigation demand in a small mediterranean catchment. Case study: Nebhana dam system, tunisia. Journal of Water and Climate Change, 11(4), 1724–1747. https://doi.org/10.2166/wcc.2019.131

Allen, R., Pereira, L., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations, 56, 26–40.

Al-Omari, A., Al-Quraan, S., Al-Salihi, A., & Abdulla, F. (2009). A water management support system for Amman Zarqa Basin in Jordan. Water Resources Management, 23(15), 3165–3189. https://doi.org/10.1007/s11269-009-9428-z

Alslevavni, i. N., & almohseen, k. A. (2017). Integrated application of (modflow) and (weap) model in nineveh province. The journal of the University of Duhok, 20(1), 680–690. https://doi.org/10.26682/sjuod.2017.20.1.59

Amin, A., Iqbal, J., Asghar, A., & Ribbe, L. (2018). Analysis of current and future water demands in the Upper Indus Basin under IPCC climate and socio-economic scenarios using a hydro-economic WEAP Model. Water (Switzerland), 10(5). https://doi.org/10.3390/w10050537

Arranz, Roberto., mccartney, M. P., & International Water Management Institute. (2007). Application of the water evaluation and planning (WEAP) model to assess future water demands and resources in the Olifants Catchment, South Africa. International Water Management Institute.

Bhatti gopal, & patel h.m. (2015). Irrigation scheduling strategies for cotton crop in semi -arid climate using weap model. Journal of Indian Water Resources Society, 35(1).

Boufala, M. H., el Hmaidi, A., Essahlaoui, A., Chadli, K., el Ouali, A., & Lahjouj, A. (2022). Assessment of the best management practices under a semi-arid basin using SWAT model (case of m'dez watershed, Morocco). Modeling Earth Systems and Environment, 8(1), 713–731. https://doi.org/10.1007/s40808-021-01123-6

Carpenter, A., & Choudhary, M. K. (2022). Water Demand and Supply Analysis using WEAP Model for Veda River Basin Madhya Pradesh (Nimar Region), India. Trends in Sciences, 19(6). https://doi.org/10.48048/tis.2022.3050

Degife, A. W., Zabel, F., & Mauser, W. (2021). Climate change impacts on potential maize yields in Gambella Region, Ethiopia. Regional Environmental Change, 21(2), 60. https://doi.org/10.1007/s10113-021-01773-3

Gontia, N. K., & Tiwari, K. N. (2010). Estimation of crop coefficient and evapotranspiration of wheat (Triticum aestivum) in an irrigation command using remote sensing and GIS. Water Resources Management, 24(7), 1399–1414. https://doi.org/10.1007/s11269-009-9505-3

Goyal, M. K., Panchariya, V. K., Sharma, A., & Singh, V. (2018). Comparative Assessment of SWAT Model Performance in two Distinct Catchments under Various DEM Scenarios of Varying Resolution, Sources and Resampling Methods. Water Resources Management, 32(2), 805–825. https://doi.org/10.1007/s11269-017-1840-1

Hagan, I. (2007). Modelling the Impact of Small Reservoirs in the Upper East Region of Ghana. Examensarete TVVR, 7.

Jabloun, by. (2012). WEAP-MABIA Tutorial A collection of stand-alone chapters to aid in learning the WEAP-MABIA module.

Momblanch, A., Shirsat, T., Kulkarni, A., & Holman, I. P. (2022). Integrating glacier flow in hydrological modelling for water resources management. Egugenereal Assembly. https://doi.org/10.5194/egusphere-egu22-6025

Najm, A. B. A., Abdulhameed, I. M., & Sulaiman, S. O. (2020). Water Requirements of Crops under Various Kc Coefficient Approaches by Using Water Evaluation and Planning (WEAP). International Journal of Design and Nature and Ecodynamics, 15(5), 739–748. https://doi.org/10.18280/ijdne.150516

Schneider, P., Sander, B. O., Wassmann, R., & Asch, F. (2019). Potential and versatility of WEAP model (Water Evaluation and Planning system) for hydrological assessments of AWD (Alternate Wetting and Drying) in irrigated rice. Agricultural Water Management, 224. https://doi.org/10.1016/j.agwat.2019.03.030

Tikariha, Y. K., & Ahmad, I. (2022). Estimation and management of irrigation water using WEAP model in Tandula reservoir command area. In R. Jha, V. P. Singh, V. Singh, L. B. Roy, & R. Thendiyath (Eds.), Hydrological Modeling: Hydraulics, Water Resources and Coastal Engineering (pp. 423–435). Springer International Publishing.

https://doi.org/10.1007/978-3-030-81358-1_32

Touch, T., Oeurng, C., Jiang, Y., & Mokhtar, A. (2020). Integrated modeling of water supply and demand under climate change impacts and management options in tributary basin of Tonle Sap Lake, Cambodia. Water (Switzerland), 12(9). https://doi.org/10.3390/w12092462

Elimination of Algae from Water Bodies – Overview

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Abstract: *A harmful algal bloom is an environmental catastrophe leading to financial losses as fishes & aquaculture die due to release of toxins causing imbalance in the ecosystem. Harmful algae bloom is a consequence of nutrient pollution. Thus, it is important to work on both the problem of eutrophication and the harmful algae bloom caused due to it. This paper reviews various treatment processes which are used for elimination of algae from water bodies.*

Key Words: *Harmful algae bloom, eutrophication, control and mitigation of algae, water bodies, elimination of algae.*

1. INTRODUCTION

'Algal bloom' refers to the rapid growth and accumulation of a large mass of phytoplankton, causing hypoxia and eventually mortality of fish and other aquatic animals (Rajendra Prasad 2019). Any hazardous or destructive event linked to microalgae that has a negative impact on tourism, fisheries, aquaculture, or public health is known as a harmful algal bloom (HAB). The type of phytoplankton involved determines the degree of toxicity and changes in the colour of the sea. These blooms are frequently seen in coastal environments & also found in open waters, brackish ecosystems, or freshwater ecosystems (Juan J. Gallardo-Rodrıguez 2018). The condition that favours HAB is sunlight, slow moving water and nutrient. Climate change is also favoring the proliferation of algae bloom (Juan J. Gallardo-Rodrıguez 2018) HABs are best managed by reducing algal cell densities, halting their rapid proliferative cycle, and minimizing their negative impacts (Zhiming Yu 2018). Cyanobacteria and Dinoflagellates cause HAB in fresh water and salt water respectively. (EPA). Red tides (accumulation of red or brown algae), blue- green algae and cyanobacteria are example of HAB. HAB is aquatic phenomena leading to discoloration of surface waters due to the rapid growth and accumulation of microalgae, several of which produce highly potent toxins (Mario R. Sengco 2004). The HAB effect human health because they have neurotoxins, hepatotoxins, cytotoxins and irritating toxins, such as lipopolysaccharides (Soukaina El Amrani Zerrifi 2018). In this review article we will try to study some of the ways that are commonly practiced to resolve the problem of HAB which is a serious environmental problem & is the most serious marine catastrophes ever which drastically effect human activity.

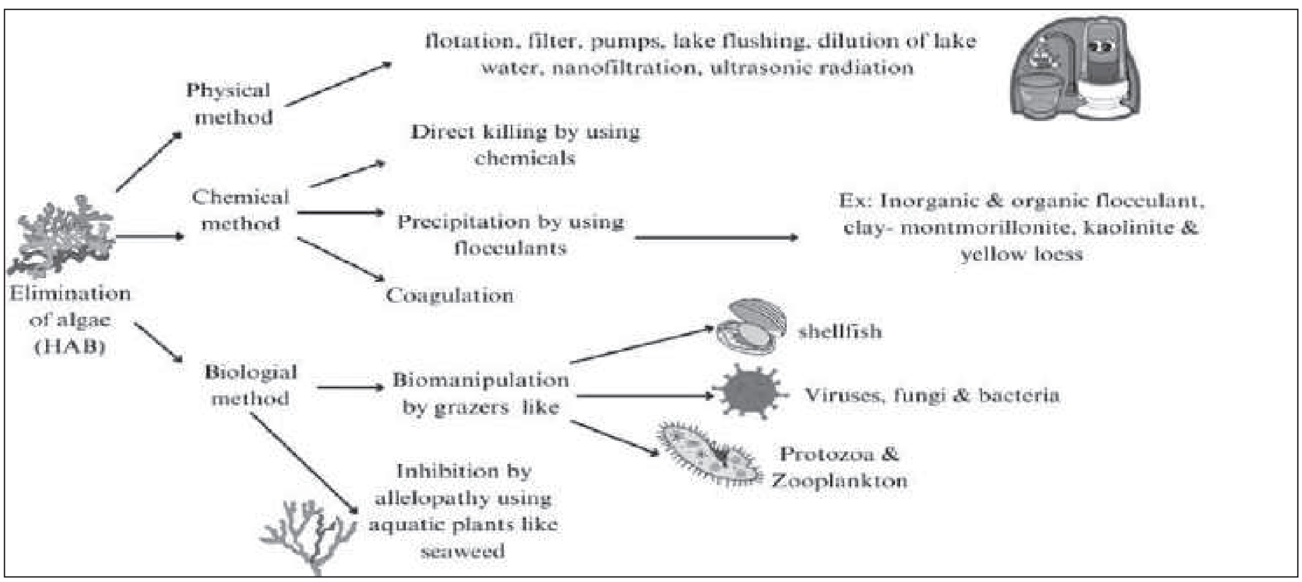

Fig. 1: *Elimination of Algae- A Graphical abstract*

2 MEASURES TO ELIMINATE ALGAE FROM WATER BODIES

The categories of harmful algal bloom mitigation are prevention and control. The goal of HAB mitigation is to decrease negative consequences after the bloom has already taken place. The current HAB-control strategies aim to lessen the impact of blooms by reducing the quantity of toxic microalgae or by removing toxins from the water column. HAB prevention involves avoiding eutrophication (Juan J. Gallardo-Rodrıguez 2018). Preventive methods aim to address the primary causes of HABs to prevent their occurrence. However, once HABs are established, adequate control and mitigation technologies and methods are needed to limit damage (Zhiming Yu 2018) .The methods include techniques that eliminate or restrict the growth of organisms that cause HAB, as well as those that physically remove cells and toxins from the water column. However, because of issues about undesired environmental effects, bloom control or suppression actions may be contentious. Four basic categories can be used to classify the majority of mitigation studies such as: physical, chemical, biological and environment measures. The following is a brief discussion of each method.

2.1 Physical Method

Majority of the physical method are preventative type and not control type which can we done by increasing exchange rate and reducing nutrient concentration (Juan J. Gallardo-Rodrıguez, 2018) .The frequently used physical method include skimming, isolation, and disruption which directly remove or isolate the algae from water (Zhiming Yu 2018). Also flotation, filters, pumps, barriers, controlled by dilution of lake water, lake flushing or ultrasonic radiation are popularly used in HAB removal. Sonication is applicable for treating huge water bodies but release dissolved organic compounds (Juan J. Gallardo-Rodrıguez 2018). However, the use of ultrasonic irradiation at 40 kHz & 60 W for 15 s effectively removed algae 12.4 % more when used with a coagulant (Liang Heng, 2006). Elimination of algae can be done by water mixing which prevents stratification using pump, hydraulic or pneumatic mixtures. The growth of photosynthetic algae can be inhibited by using floating covers (Juan J. Gallardo-Rodrıguez, 2018). The rapid filtration without coagulants can remove almost 50% algae depending on the species and their size. It is suggested in study that microstraining is a pretreatment ahead of a complete flocculation-settling-filtration line. Many researchers suggest use of multimedia filter with primary treatment using microstrainers, flocculators to be more efficient over single or dual media filter (P. Mouchet, 1998). The low pressure air flotation can be fitted on ferryboat which efficiently remove 99% Chl-a, 80% COD and 97% TP removal (Hang Vo-Minh Nguyen, 2018). Nanofiltration is effective in removal of algal metabolites (M. B. Dixon 2010). The dispersed air flotation process helps in removal of algae where electrostatic interaction of collector and algae surface helps in removal of algae (Y.M. Chen, 1998). The advantage of physical method is that it leads to no secondary pollution, good results for small water bodies, easy to operate, environmental friendly. The disadvantage are costly, energy consuming, injurious to species that are not target (Juan J. Gallardo-Rodrıguez 2018) lysis release toxins in water and ineffective when applied in large volumes of water (Zhiming Yu 2018). The Fig. 2 summarizes the complete physical method

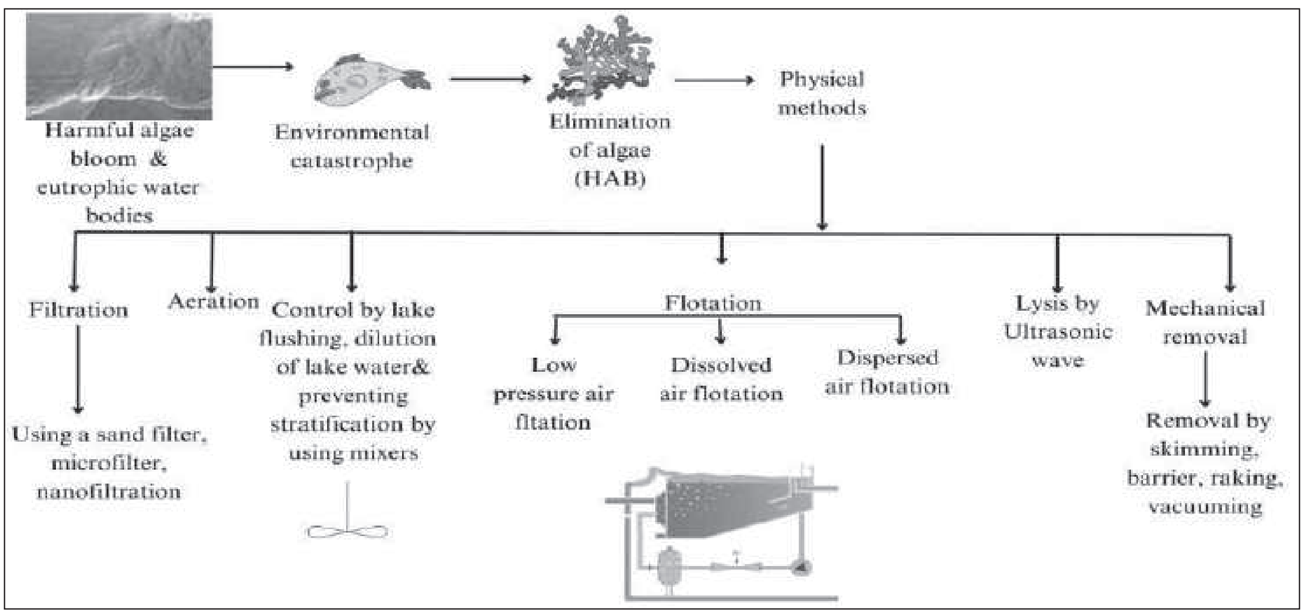

Fig. 2: *Physical method*

2.2 Chemical Method

The chemical methods work on the principle of direct killing or precipitating algae through floc formation. In this method we use several chemical compounds as algicides (any chemical added to water which is toxic to, and kills algae and/or cyanobacteria) or algistats (any chemical or additive, added to water that inhibits or retards the growth of algae, either directly, or by chemical modification of the water column) (Jiajia Fan, 2013).The chemicals used for direct killing can be inorganic chemicals like cupric sulphate, hydrogen peroxide, hypochloric acid, chlorine, sodium hypochlorite, sodium percarbonate, chlorine (Jeanine D. Plummer 2002) and ozone, as well as organic algicides like hexadecyl trimethyl ammonium bromide (HDTMA), sophorolipid, carboxylic acid, organic amine, ketone and aponin (Zhiming Yu 2018). However, use of cupric sulphate is illegal due to its toxic effect on the entire ecosystem and leads to heavy metal accumulation. In the process of precipitation through floc formation can be achieve by using organic, inorganic and natural mineral flocculants. Iron and aluminum sulphate, ferric chloride are example of inorganic flocculants. Surfactant and polymer are commonly used organic flocculant (Zhiming Yu 2018). Hydrogen peroxide (H_2O_2) has proven to be an environmentally friendly oxidant. Natural attapulgite (N-AT) and modified attapulgite (M-AT) were utilized to assess the efficacy and processes of flocculation in freshwater harboring dangerous algal blooms (Yi Tang 2011). Clay such as montmorillonite, kaolinite and yellow loess is a very popular flocculant which along with various chemicals such as polyaluminium chloride (PAC), $Ca(ClO)_2$, $AlCl_3$, $FeCl_3$ (Zhiming Yu 2018). Clay has proven to be effective and has been used in countries like Japan, China, South Korea, United states, Sweden, Australia (Mario R. Sengco 2004).A comparative study of various coagulants Poly Ferric Sulphate (PFS), Ferric sulphate(FS), Aluminium sulphate (AS) and Poly Aluminium Chloride (PAC) conclude that PFS was superior to other coagulants due to its cation species which were more highly charged (Jia-Qian Jiang 2018). The advantage of chemical method is quick, effective, operability. The disadvantages include the adverse effect on the environment by secondary pollution, non specific and costly (Zhiming Yu 2018). The Fig. 3 summarizes the complete chemical method

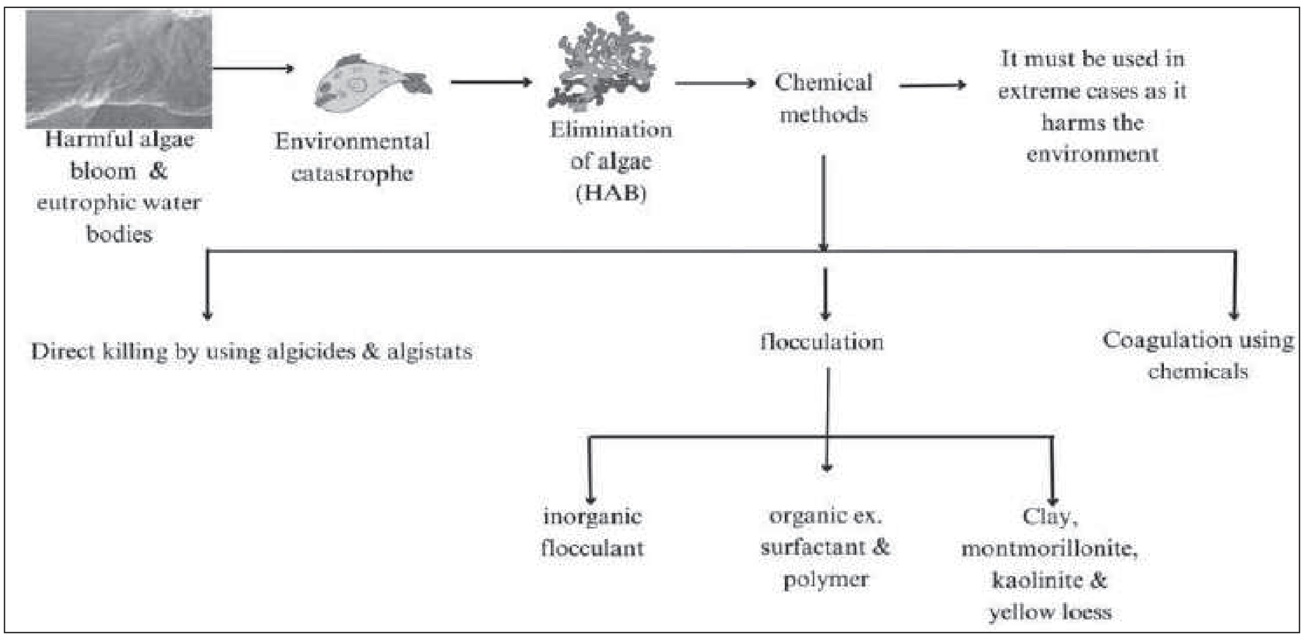

Fig. 3: *Chemical method*

2.3 Biological Method

Enzymatic or parasitic effects on microbes, nutritional competition, or parasites are frequently used in biological techniques to manage HABs. Macroalgal or seagrass allelopathic effects or grazing by marine protozoa, zooplankton, and filter-feeding shellfish. However, bioaccumulation of toxic algae from shellfish may harm human beings. Biomanipulation is a technique which specific to species which involves the introduction of new grazers and rivals of cyanobacteria. Microorganisms (viruses, bacteria, fungi, and protozoa) as well as macrophytes and periphyton as well as herbivorous fish (silver and bighead carp) and algae are employed. Allelochemicals or secondary metabolites released by plants, have strong application prospects in the field of water ecological restoration because of their excellent biocompatibility, biodegradability, clear algal inhibitory impact, and minimal ecological harm. It can be used in algal inhibition (Benhang Li 2020). The advantages of biological processes usually have no negative effects on non-HAB species, can be species-specific, and rarely generate secondary pollution. The disadvantage is that it is challenging to apply biological approaches to control HABs when quick action is required due to the enormous challenges in cultivation, transportation, and timeliness when these methods are used in the field, costly, availability of area, imbalance in the trophic chain. The Fig. 4 summarizes the complete biological method.

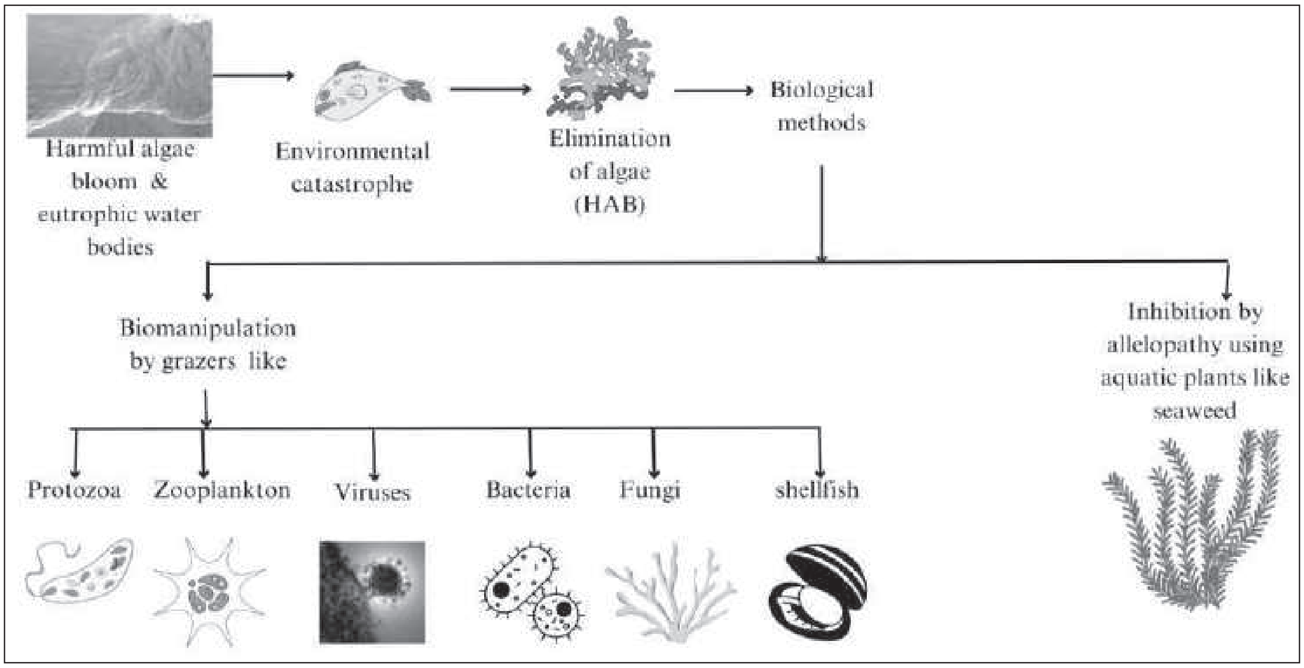

Fig. 4: *Biological method*

2.4 Environmental Method

This category comprises tactics that alter the environment physically or chemically in order to either harm the target species or improve a native or introduced biological control. Examples include efforts to change water circulation or residence times through dredging or opening of channels, manipulation of nutrient levels in coastal waters through pollution control policies, and aeration or other efforts to disrupt stratification, thus changing the make-up of phytoplankton communities (Zhiming Yu 2018).

3. CONCLUSION

Harmful algae bloom (HAB) is a threatening environmental catastrophe occurring due to nutrient pollution and is a result of eutropication. It causes dead of fishes and destroys the aquaculture of the water body leading ill effects on financial, social and health of the region. All the measure try to remediate the issue but there is need to take preventive measures to stop eutrophication by proper handling of surface runoff into water bodies in order to prevent the nutrient pollutant. Control measures like physical, chemical and biological measures should be selected only after analyzing risk due to their disadvantages.

4. REFERENCES

A.K. Misra, P.K. (2015). "Modeling the impact of awareness on the mitigationof algal bloom in a lake." *Springer* .

Anderson, D.M. (2009). "Approaches to monitoring, control and management of harmful algal blooms (HABs)." *Ocean & Coastal Management* .

Benhang Li, Y.Y. (2020). "A review: Application of allelochemicals in water ecological restoration algal." *Elsevier* .

EPA, U. (n.d.). *Cyanobacterial Harmful Algal Blooms (Cyano Key Words: Harmful algae bloom, eutrophication, control and mitigation of algae, water bodies, elimination of algae. HABs) in Water Bodies*.

Hang Vo-Minh Nguyen, J.K. (2018). "A Case Study of Low Pressure Air Flotation Ferryboat for Algae Removal in Korean Rivers and Lakes." *Journal of Industrial and Engineering Chemistry* .

Jeanine D. Plummer, J.K. (2002). "Effects of chlorine and ozone on algal cell properties and removal of algae by coagulation." *Journal of Water Supply: Research and Technology—AQUA* .

Jiajia Fan, L.H. (2013). "Evaluating the effectiveness of copper sulphate, chlorine, potassium permanganate,hydrogen peroxide and ozone on cyanobacterial cell integrity." *Water Research* .

Jia-Qian Jiang, N.J. (2018). "Comparison of polyferric sulphate with other coagulants for the remov al of algae and algae-derived organic matter." *water science technology* .

Juan J. Gallardo-Rodrıguez, A. A.-V.-R.-F.-J. (2018). "A critical review on control methods for harmful algal blooms." *Reviews in Aquaculture* .

Liang Heng, N. J.-j. (2006). "Algae removal by ultrasonic irradiation–coagulation." *Elsevier* .

M.B. Dixon, C.F. (2010). "Nanofiltration for removal of algal metabolites and effects of fouling." *Water Science & Technology- WST* , 1189.

Mario R. Sengco, D.M. (2004). "Controlling Harmful Algal Blooms Through Clay Flocculation." *J. Eukaryot. Microbiol., Vol. 51, No. 2,* .

Mili Pal, P.J. (2020). "Biotic control of harmful algal blooms (HABs): A brief review." *Journal of Environmental Management* .

P. Mouchet, V. (1998). "Solving algae problems: French expertise and world-wide applications." *J Water SRT*.

R.K. Henderson, S.A. (2008). "Successful Removal of Algae through the Control of Zeta Potential." *Separation Science and Technology* .

Rajendra Prasad, S.P. (2019). "Algal Blooms and Phosphate Eutrophication of Inland Water Ecosystems with Special Reference to India." *International Journal of Plant and Environment* .

Soukaina El Amrani Zerrifi, F. E. (2018). "Seaweed Bioactive Compounds against Pathogens and Microalgae: Potential Uses on Pharmacology and Harmful Algae Bloom Control." *Marine drug* .

USEPA. (n.d.). *Harmful Algae Blooms*. Retrieved from https://www.epa.gov/nutrientpollution/harmful-algal-blooms

Y.M. Chen, J. L.-H. (1998). "Flotation removal of algae from water." *Colloids and Surfaces B: Biointerfaces* .

Yi Tang, H.Z. (2011). "Flocculation of harmful algal blooms by modified attapulgite and its safety evaluation." *Water research* .

Zhiming Yu, X.S. (2018). "Mitigation and control of harmful algal blooms." In *In global ecology and oceanography of harmful algal blooms* (p. 403 to 423). springer,cham.

Effects of Arsenic on Human Health: Treatment In Groundwater – A Review

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Abstract: *Arsenic toxicity has been influencing the people all over the world. It commonly occurs in natural water as arsenite and arsenate. It has been causing cancerous diseases in different organs of the human beings. Groundwater samples collected from different locations and analysed by different researchers have shown that arsenic concentrations have exceeded the norm prescribed by World Health Organization. High arsenic concentration has also been found in blood samples. In this paper, ground water samples and blood samples collected and analysed for arsenic concentration by different researchers have been discussed. Its effects on human health have been explained. Arsenic removal efficiencies by different treatment techniques like reverse osmosis, use of laterite as arsenic adsorbent, use of irons, chemisorption filtration, biological treatment, membrane separation, electrocoagulation and water hyacinth have also been discussed.*

Key Words: *Arsenic, treatment, effects, groundwater, human health*

1. INTRODUCTION

Arsenic beyond permissible level in surface and ground waters has become a major health problem all around the world (Koˇsuti´c et al. 2005). The World Health Organization (WHO, 2011) recommends the limitation of arsenic is 10 µg/L in drinking water. Arsenic has been commonly found as arsenite [As(III)] and arsenate [As(V)]. Arsenite compounds are 50 times more toxic than arsenates, and arsenite is more soluble in water than arsenate at the same duration of time. Arsenates are adsorbed quite strongly on various mineral surfaces, particularly iron/ oxide hydroxide, while the adsorption capacity of arsenite is poor (Phuong et al. 2017).

Contamination of groundwater with arsenic is a major environmental concern affecting the health of some 140 million people in over 50 countries worldwide (WHO, 2018). Arsenic is mobilized by natural weathering reactions, biological activity, geochemical reactions, volcanic emissions. In addition to mobilization under natural conditions, mining activities, combustion of fossil fuels, use of arsenic pesticides, herbicides, and crop desiccants and use of arsenic additives to livestock feed create additional impacts (Mohan & Pittman, 2007). Also mobilized by human interventions, such as use of fertilizers, waste disposal, and industrial manufacturing (Duker et al. 2005). Globally, the primary route of human exposure to arsenic is through the ingestion of contaminated drinking water, or irrigation water that makes its way into food through plant roots (WHO, 2018). According to Mudhoo et al. (2011), in India, the presence of arsenic in groundwater has been reported from several states, including West Bengal, Jharkhand (Sahibganj district), Bihar, Ganga Plains in Uttar Pradesh, Assam, Impahal ricer's Food Plains in Manipur, and some pockets in Chhatisgarh. The School of Environmental Studies, Jadavpur University, Kolkata, India did extensive work on arsenic monitoring of groundwater and its impact on human health. In West Bengal, arsenic contamination in groundwater was first detected in 1978 and the first arsenic-poisoned patient was found in West Bengal in 1983.

Inorganic arsenic is extremely toxic, both acute and chronic. Initially, it enters into the human body through ingestion, inhalation, or skin absorption (Saha et al. 1999). Ingested inorganic arsenic does cause cancers of the bladder, kidney, lung, and liver (Bates et al. 1992). The arsenic poisoning in India has caused various illness in the population such as hyperkeratosis in sole and palm, skin diseases, melanosis, swelling in lower limbs, neuropathy, gastritis, constipation, dysentery, loss of appetite, chronic lung disease, irregular menstrual cycle in females, thyroid disorders, gangrene, infertility in males as well as in females and the non-communicable disease like cancer. The arsenic in vivo interacts with the various enzymes that are crucial for the normal metabolic functions of the body and disrupts their functions causing various types of diseases (Krassas, 2000, Haque et al. 2003, Rahman et al. 2019). In this paper, the effects of arsenic on human health and its treatment methods adopted by the different researchers have been explained.

2. ARSENIC CONCENTRATION AND ITS EFFECTS ON HUMAN HEALTH

To assess the concentration of arsenic in groundwater and its impact on health, Kumar et al. (2021) randomly collected 80 groundwater samples from the handpumps of the households of Tilak Rai Ka Hatta village, Buxor, Bihar, India and 80 blood samples from the same household to know the status of the arsenic contamination in the habitants. Eighty groundwater samples analysis report showed very high level of arsenic contamination, as the maximum level observed was 1908 µg/L. In 86% of the handpump water samples, arsenic contamination was found to be more than the WHO permissible limit while only 14% of handpump samples had normal levels < 10 µg/L. Out of total assayed 80 blood samples, 29 (36%) blood samples were having arsenic contamination levels < 1 µg/L (which is WHO-recommended threshold line for blood arsenic level) (WHO 2011), while the rest 51 blood samples (64%) were having blood arsenic levels above the normal level (> 1 µg/L). The arsenicosis symptoms such as keratosis, melanosis and hyperpigmentation in sole and palm were observed in the village population since they were consuming very high arsenic concentrated drinking water. Most of the exposed village people exhibited arsenicosis symptoms such as rain drop pigmentation, melanosis, leucomelanosis in trunk, blackening of tongue and tumorous lump growth on the body. In the interviewed individuals, it was found that the village population had significant skin manifestations such as keratosis in sole and palm, melanosis and other skin manifestations. The other internal organ symptoms observed were related to gastritis, liver-related problem, loss of appetite constipation, hormonal imbalance, etc. Children below 12 years had the symptoms of keratosis in sole and palm. Twelve cancer cases were observed in 2 years of the study time in the population especially with skin cancer (squamous cell carcinoma), skin melanoma, bladder cancer, stomach cancer, liver cancer, breast cancer, leukaemia and lymphoma. All the cancer patients exhibited the symptoms of arsenicosis.

Rahman et al. (2019) carried out studies in Simri village of Buxar district of Bihar, India. The village is situated approximately 1.65 km away from the banks of the river Ganga. They collected 323 water samples randomly from the village in duplicates from hand pumps of each household situated at every 50 m of distance. They observed maximum arsenic concentration in groundwater sample was 1,929 µg /L. Total 170 blood samples of Simri village people were analyzed and the maximum arsenic concentration in blood sample of the village people reported was 664.7 µg/L that is ultimately high level of arsenic in blood ever reported. The village people exhibited typical symptoms of arsenicosis like hyperkeratosis in sole and palm, hyper-pigmentation in palm as they were drinking very high concentration of arsenic contaminated drinking water. Many village people exhibited suspected cancerous nodes in the neck region (suspected lymphoma cancer). Most of the village people had health-related problems like gastritis and flatulence, constipation, anemia, loss of appetite, breathlessness, mental disability, etc., Moreover, there was reporting of cancer cases like breast cancer, liver cancer, gall bladder cancer, thyroid cancer, colorectal cancer cases, etc.

Nduka et al. (2006) selected five refuse biggest dump sites named as A (Ring Road Amaenyi), B (Behind Amaku General Hospital), C (Bishop Crowther), D (Prisons Amawbia) and E (Kwata (Slaughter) at Awka, Nigeria for the study. These sites are mainly used for the dumping of domestic and sundry refuse. The soil near the dump sites are fine to medium sand in texture. From each site, four soil samples were collected. Out of which one from ground surface and another from 0.45 m, 0.90 m and 1.35 m depth. The soil samples were tested for ten heavy metals like cobalt, arsenic, chromium, cadmium, nickel, zinc, lead, copper, manganese, and iron) and three other elements such as magnesium, sodium, and potassium using an atomic absorption spectrophotometer. Organic matter was also determined. In the soil samples, organic carbon ranged from 0.84% to 1.78%, and organic matter from 1.45 to 3.07. The sum of total metals in all the four soils for each refuse dump site were calculated. Site A and C had the highest concentration levels of arsenic (2,300 ppm) and lead (2,467 ppm), respectively. Site D had highest level of both iron (72,200 ppm) and sodium (3,561 ppm). Site E had the lowest level of lead (572 ppm). Metals concentration varied with respect to depth. They reported that heme, a coloured pigment of haemoglobin called ferroprotoporphyrin, contains iron as its central element; chlorophyll, a green pigment containing magnesium; hemocyanins in mollusc, alcohol dehydrogenase in horse liver, and hemovanadin, an oxygen carrier found in sea squid and organotin compounds widely used as pesticides and fungicides and copper arsenate used as wood preservatives. All these give rise to copper, zinc, vanadium, tin, and arsenic.

3. TREATMENT OF ARSENIC

Many researchers have used different techniques for the treatment of arsenic in water, which are explained as under:

3.1 Reverse Osmosis (RO)

To check the filtration efficiency of RO for arsenic removal, George et al. (2006) surveyed 102 homes and identified that residents of 19 homes were using RO units to filter private well water. They observed that all prefiltration arsenic levels were higher than the new US Environmental Protection Agency's (USEPA) standard of 10 µg /L. The average arsenic concentration before filtration was 443 µg /L (range = 36–2,363 µg /L), and the average arsenic concentration after filtration was 87 µg /L (range = <10–641 µg /L). The average absolute reduction in arsenic concentration was 356 µg /L (range = - 2–2,358 µg /L). The average percent reduction with filtration was 79% (range = -1– > 99%). In 9 of 19 homes (47%), arsenic levels were reduced to a level below the USEPA standard of 10 µg /L. In the remaining 10 homes (53%), arsenic concentrations after RO filtration remained above 10 µg /L. It was found that more than half of the RO units evaluated did not reduce arsenic levels below the US public water arsenic standard, and in many homes, arsenic concentrations were not reduced below 100 µg /L. The findings provide evidence that RO filters do not guarantee safe drinking water.

3.2 Laterite as Adsorbent

Phuong et al. (2017) used laterite for the treatment of groundwater. Samples collected from groundwater had arsenic concentration of 0.57 mg/L, which was 57 times higher than the WHO standard drinking water (10 µg/l). The chemical composition, surface morphology and surface area of the adsorbent material (laterite) were analysed. The laterite rock samples were thoroughly washed with tap water to remove unwanted impurities (organic impurities, worms, sand, dust and dried). Then, the laterite rock samples having size range of 0.15-0.42 mm had 6.52% Fe content. They were screened, thoroughly washed (15-20 times) with tap water to remove red iron, and then washed with distilled water. Finally, the powder was dried in a hot oven at 110°C for overnight. Groundwater was passed through these powder laterites. They concluded that laterite consisted of O (62.24%), Fe (11.07%), Al (8.49%) and Si (7.18%). The heterogeneous and porous surface morphology, the relatively large specific surface area (30,712 m^2/g), indicated that laterite has many characteristics of a material with good adsorption capacity. Adsorption experiments showed that the treatment efficiency is 99.91%. Laterite is a potential material for the treatment of arsenic in water.

3.3 Irons (iron slag, nails and mesh)

Hayder et al. (2018) developed a Pakistan Arsenic Filter (PAF). Three different forms of iron like iron slag, nails, mesh were used in the study. To prepare the PAF, locally available plastic bucket having 32 cm diameter and volume 25 litters was used. Diffuser plates were installed in the bucket to hold iron materials. A PPRC pipe with tap was fitted in the buckets in such a way that water level could be adjusted and collect samples after treatment. For preparation of filter bed in bucket, a 5 cm thick gravel layer (6-15 mm size) was filled at the bottom of the bucket, above this layer 15 cm thick sand layer was placed. Above the sand layer, 2 cm resting water level was maintained. One-kilogram weight of different forms of iron (nails, mesh and slag) was placed in the diffuser plate kept at the top of the bucket. PAF run was conducted for a time period of 8 weeks. Tube wells water was used for the treatment. They concluded that iron mesh has the highest arsenic removal efficiency compared to nails and slag, which might be due to larger surface area of iron mesh producing more ferric hydroxide (arsenic adsorbent). It was suggested that PAF constructed using iron mesh and sand combination may be deployed at locations where arsenic concentration ranges within 50 ppb to 100 ppb.

3.4 Chemisorption Filtration

Solozhenkin et al. (2007) used different sorbents like low-cost polymeric material consisting of polystyrene granules with a coarseness of 3-4 mm and a porosity of 0.37; granules of a new microporous polymer synthesized by a high intraphase emulsification of polyVVFE with a coarseness of 3-4 mm and a porosity of 0.37. This microporous material consists of a larger volume of pore-forming liquid dispersed in a relatively small volume of monomer. Styrene mixed with cross-linking divinylbenzene was used as a monomer. The structure of poly VVFE is characterized by the presence of many cells joined together by the smallest pores. The sizes of cells and pores can be controlled by changing the stirring time, the type of emulsion stabilizer, the nature of a monomer, and the water/monomer ratio. This material has as yet not been used in treating drinking and waste water; Calcium alginate granules, which is a biopolymer extracted mainly from brown algae. A biopolymer deposit (2 g) was dispersed in 100 ml of nonionized water and mechanically stirred to give a film of viscous solution. Calcium alginate granules were obtained by introducing droplets of a water solution of sodium alginate into the continuously stirred calcium chloride solution to obtain spherical particles. For the formation of gel granules, approximately one drop of the polymer solution was dispersed per second in 500 ml of $CaCl_2$ with moderate stirring (60 rps), because granules were sensitive to the hydrodynamic actions.

They concluded that the main parameters of the processes of arsenic extraction by polystyrene have been found: pH 7.0; linear rate 1.4 m/h; iron to the coating concentration $[Fe]_{coat}$ = 0.1 M; $[As]_0$ = 50 µg/l; and processing with solutions in an amount of 20 volumes of the sorption bed. Under these conditions, 85% of As(III) was removed, while As(V) was removed completely. The maximum permissible arsenic content (m.p.c.) point <10 µg/L was achieved after treating with solutions taken in an amount of 250 volumes of the sorbent bed, while the arsenic removal was more efficient than with the polystyrene granules. It was found that the amount of iron coated different samples varied from 23 to 93 (mg Fe)/(g polyVVFE). The most efficient granules were prepared after preliminary iron absorption by calcium alginate, followed by coating them with iron hydroxide. For a 10-min stay of contaminated water, the m.p.c. point (10 µg/l) was achieved upon treating the reaction zone with the As(V) solutions taken in an amount of 230 volumes of the sorbent bed. Compared to the case of As(III) solution, a volume equal to 45 volumes of the sorbent bed was taken to achieve the m.p.c. point. It has been found theoretically that, to achieve 20% of m.p.c., the sorbent bed with a sorption capacity of 13.75 (µg As)/(g wet alginate granules) or 2.91 (mg As)/(mg Fe) is required. To achieve the As = 10 µg/l concentration in a flow, a 76-s contact and a consumption of 0.45 (kg algenate)/ dm^3 are necessary. Adsorptive filtration is an efficient technology for arsenic removal. It offers certain advantages over the existing technologies; it confines the production of poisonous sludges, extends the surface area for adsorption, and can be used for removing low concentrations of arsenic from ground water.

3.5 Biological Treatment

Murugesan et al. (2006) examined the removal capacity of tea fungus (a waste produced during black tea fermentation) for the metal ions of ground water samples. Autoclaved tea fungal mat and autoclaving followed by $FeCl_3$ pre-treated tea fungal mat were used for removal of As(III), As(V) and Fe(II) from ground water sample collected from Kolkata, West Bengal, India. The results revealed that the $FeCl_3$ treated fungal mat (FM) and autoclaved fungal mat are efficient in removing As(III), As(V) and Fe(II) from ground water sample respectively. $FeCl_3$ treated FM works better than nontreated mat because iron has an affinity towards arsenic in forming arsenic-iron oxides. The biosorption rate tends to increase with the increase in contact time and adsorbent dosage. $FeCl_3$ pre-treated and autoclaved fungal mats removed 100% of As(III) and Fe(II) after 30 min contact time and 77% of As(V) after 90 min contact time. The optimum adsorbent dosage was 1.0 g/50 mL of water sample. The results revealed that the $FeCl_3$ pre-treated fungal mat could be used as an effective biosorbent for As(III) and As(V); autoclaved fungal mat for Fe(II) removal from ground water sample. In batch mode studies, the adsorption was dependent on contact time, initial metal ion concentration and biosorbent dosage. The adsorption of metal ions followed the Freundlich isotherm model. The rate constant data would be useful for the designing of water treatment plants. The tea fungal mat produced during black tea fermentation was exploited for metal removal. Moreover, the fungal mat is easily biodegradable. After adsorption studies, the metals can be desorbed by re-suspending the tea FM in flask containing ٥٠ mL of NaOH (0.1–0.5 N) and agitated for different time intervals to fix the equilibrium time for maximum desorption of metal ions. Later the tea FM can be separated from the NaOH solution. So, after adsorption process, the metals can be desorbed from the mat and the mat can be easily degraded which is not possible in chemical adsorbents.

3.6 Membrane Separation

Koˇsuti´c et al. (2005) studied the removal of arsenic and pesticides from natural ground water. For this, two types of thin-film polyamide nanofiltration (NF) membranes, NF270 and NF_c (FilmTec Corporation, Dow Chemical Comp., Midland MI; the latter membrane type was obtained from the manufacturer under this name and it is called NFc throughout the text), and a thin-film polyamide reverse osmosis membrane CPA2 (Hydranautics, Oceanside CA) were used. The membrane samples of 13.2 cm^2 surface area were used throughout the work. The nanofiltration membranes and a comparing reverse osmosis membrane were first examined using sodium dibasic arsenate solution and judged against their performances using sodium chloride and sodium sulfate solutions. Reverse osmosis/nanofiltration experiments were carried out in a laboratory. The rejections of the sodium dibasic arsenate as well as the arsenate anion from natural ground water by the nanofiltration membranes are satisfactory high, but not much below the rejections of the reverse osmosis membrane. The NF270 type nanofiltration membranes exhibit the superior permeation flow rate values, Q_p (kg/m^2/h), that are more than five times higher than the corresponding values of the reverse osmosis CPA2 membrane. The prevailing mechanism in retention of ions by the negatively charged nanofiltration membranes is the charge exclusion, whereas the reverse osmosis membrane exclude the anions mostly by size. The size exclusion mechanism is also important but not sufficient for the uncharged organic molecule rejection by the nanofiltration membranes. Its role should be modified by the effect of membrane/solute/solvent interactions, emphasizing the importance of the membrane material and the membrane pore size distribution (PSD) for the uncharged solute rejections. The rejections of pesticides are reasonably high and pretty well follow the order of their molecular sizes. Some specific physicochemical phenomena such as the hydrophobicity of the pesticide molecules and/or their dipole moments should be also considered in order to understand their rejection by the nanofiltration membranes. The outstanding permeation rate values of the NF270 membranes in relation to the reverse osmosis membrane promises a noteworthy decrease of energy consumption and energy costs for the process when using these membranes. This should be confirmed by the future pilot-scale tests.

3.7 Electrocoagulation

Wan (2010) conducted batch electrocoagulation experiments in the laboratory using iron electrodes. In the experiments, effects of pH, initial arsenic concentration and oxidization state, and concentrations of dissolved phosphate, silica and sulfate on the rate and extent of arsenic removal were found out. The effect of water chemistry and treatment time were interpreted using adsorption modeling and a rate model for coagulant production and arsenic adsorption. The iron generated during electrocoagulation precipitated as lepidocrocite (γ-FeOOH), except when dissolved silica was present. Arsenic was removed by adsorption to the lepidocrocite. Arsenic removal was slower at higher pH. When solutions initially contained As(III), a portion of the As(III) was oxidized to As(V) during electrocoagulation. As(V) removal was faster than As(III) removal. The presence of 1 and 4 mg P/L of phosphate inhibited arsenic removal, while the presence of 5 and 20 mg SiO2/L of silica or 10 and 50 mg $SO4^{2-}$ /L of sulfate had no significant effect on arsenic removal. For most conditions examined in this study, over 99% arsenic removal efficiency was achieved. Electrocoagulation experiments for arsenic removal were performed using iron electrodes at pH 5, 7 and 9. The effect of water chemistry and treatment time were interpreted using adsorption modeling and a rate model for coagulant production and arsenic adsorption. Equilibrium As(V) adsorption was investigated in batch experiments as a function of dissolved As(V) concentration, pH, and phosphate using lepidocrocite generated by electrocoagulation. A surface complexation model was then developed that successfully simulated equilibrium As(V) adsorption. As(V) adsorption onto the lepidocrocite generally decreased with increasing pH from 4 to 10. The presence of 1-4 mg P/L of phosphate inhibited As(V) adsorption. The rate model simulated the overall arsenic removal by electrocoagulation well by using Faraday's law to predict coagulant production and a rate expression for arsenic adsorption. A maximum arsenic removal efficiency of over 99% was achieved during both the electrocoagulation and equilibrium adsorption experiments.

3.8 Water Hyacinth

Misbahuddin & Fariduddin (2002) used mid-sized water-hyacinth plants having many large fibrous roots for the treatment of arsenic. Arsenic-contaminated water was drawn from the shallow tube wells. Prior to the initiation of each experiment, whole plants (i.e., fibrous roots, leaves, and leaf stalks) were cleaned with water. The dead parts of leaves, leaf stalks, and roots were removed. In this experiment, 0.5-0.6 kg of water hyacinth in a bucket that contained 10 L of water and 400 ppb arsenic was used. Cut-up pieces of either leaves, leaf stalks, or fibrous roots in buckets that contained arsenic contaminated water were also placed to study the effects of the plant parts in arsenic removal. All the buckets were placed in an open space with adequate fresh air and sunlight. After 1, 2, 3, 6, and 24 hr of exposure, the water in each bucket was stirred, and a 35-ml water sample was taken for estimation of arsenic level. The plant material was homogenized and digested by 20 ml of nitric acid, 5 ml of sulfuric acid, and 5 ml of hydrochloric acid. The amounts of arsenic present in the water and the plant were estimated with the silver diphenyl dithiocarbamate (SDDC) method. It was observed that the whole plant removed arsenic 100% and fibrous roots 81% at 6 hours. The leaves and leaf stalks did not remove the arsenic. The effectiveness of water hyacinth was greater in the sunlight.

4. CONCLUDING REMARKS

Drinking of arsenic contaminated groundwater causes various types of cancerous diseases in human being. Different researchers have used different techniques for the treatment of arsenic in groundwater. Reverse osmosis filter used at different homes do not guarantee the safe drinking water. Laterite as adsorbent has proved to be 99% of arsenic removal from ground water. Iron mesh due to larger surface area produce more ferric oxide (arsenic adsorbent) and works as good adsorbent in minimization of arsenic. Chemosorption filtration has contributed 85% of As(III) removal and As(V) as complete removal. Biological treatment in the form of autoclaved tea fungal mat followed by $Fecl_3$ pre-treated fungal mat are efficient in removal of As(III), As(V) and Fe(II) from groundwater. Nanofiltration membranes can proved as a good option for arsenic removal. Electrocoagulation showed 99% arsenic removal. Water hyacinth is a good phytoremediation technique for the removal of arsenic contaminated groundwater.

5. REFERENCES

Bates M.N., Smith A.H. and Hopenhayn R.C. (1992) Arsenic ingestion and internal cancers: A review, Am J Epidemiol, 135: 462-76.

Duker A.A., Carranza E. and Hale M. (2005) Arsenic geochemistry and health. Environ. Int., 31(5): 631-641.

George C.M., Smith A.H., Kalman D.A. and Steinmaus C.M. (2006) Reverse osmosis filter use and high arsenic levels in private well water, Arch Environ Occup Health, 61(4): 171-175.

Haque R., Mazumdar D.N.G., Samanta S., Ghosh N., Kalman D. and Smith M.M. (2003) Arsenic in drinking water and skin lesions: dose-response data from West Bengal, India, Epidemiology, 14(2): 174–182.

Hayder S., Ahmed T. and Tariq M. (2018) Arsenic: A low-cost household level treatment for rural settings in developing countries, Journal of Pollution Effects & Control, 6(3): 1-5.

Koˇsuti´c K., Furaˇc L., Sipos L. and Kunst B. (2005) Removal of arsenic and pesticides from drinking water by nanofiltration membranes, Sep. Purif. Technol., 42: 137–144.

Krassas G.E. (2000) Thyroid disease and female reproduction, Fertil. Steril., 74(6): 1063–1070.

Kumar A., Rahman M.S., Ali M., Kumar R., Niraj P.K., Singh S.K., Kumar D., Rashmi T., Bishwapriya A., Akhouri V., Chand G.B., Sakamoto M. and Ghosh A.K. (2021) Assessment of arsenic exposure and its mitigation intervention in severely exposed population of Buxar district of Bihar, India, Toxicol Environ Health Sci., 13: 287–297.

Misbahuddin M. and Fariduddin A. (2002) Water hyacinth removes arsenic from arsenic-contaminated drinking water, Archives of Environmental Health: An International Journal, 57(6): 516-518.

Mohan D. and Pittman C.U. (2007) Arsenic removal from water/wastewater using adsorbents—A critical review, J. Hazard. Mater, 142 (1–2): 1-53.

Mudhoo A., Sharma S.K., Garg V.K. and Tseng C.H. (2011) Arsenic: An overview of applications, health, and environmental concerns and removal processes, Crit. Rev. Environ. Sci. Technol., 41(5), 435-519.

Murugesan G.S., Sathishkumar M. and Swaminathan K. (2006) Arsenic removal from groundwater by pre-treated waste tea fungal biomass, Bioresour. Technol., 97: 483–487.

Nduka J.K.C., Orisakwe O.E., Ezenweke L.O., Abiakam C.A., Nwanguma C.K. and Maduabuchi U.J.M. (2006) Metal contamination and infiltration into the soil at refuse dump sites in Awka, Nigeria, Arch Environ Occup Health, 61(5): 197-204.

Phuong N.T.T., Trang D.T.K. and Luu T.L. (2017) Arsenic treatment in groundwater in Mekong delta using laterite absorbent, Sci. J. Chem., 5(6): 95-100.

Rahman M.S., Kumar A., Kumar R., Ali M., Ghosh, A.K. and Singh S.K. (2019) Comparative quantification study of arsenic in the groundwater and biological samples of Simri village of Buxar district, Bihar, India, Indian J. Occup. Environ. Med., 23 (3): 126-132.

Saha J.C., Dikshit A.K., Bandyopadhyay M. and Saha K.C. (1999) A review of arsenic poisoning and its effects on human health, Crit. Rev. Environ. Sci. Technol., 29(3): 281-313.

Solozhenkin P.M., Zouboulis A.I. and Katsoyiannis I.A. (2007) Removal of arsenic compounds from wastewater by chemisorption filtration, Theor. Found. Chem. Eng., 41(5): 772–779.

Wan W. (2010) Arsenic Removal from Drinking Water By Electrocoagulation. All Theses and Dissertations (ETDs), 511. https://openscholarship.wustl.edu/etd/511

WHO (2011) Guidelines for drinking-water quality—4th ed. Geneva: World Health Organization.

WHO (2018) World Health Organization, Arsenic [Fact sheet no. 372]. Retrieved from http://www.who.int/mediacentre/factsheets/fs372/en/

Acute Toxicological Effect of Composite Industrial Effluent on Zooplankton (Moina sp.)

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Abstract: *Composite industrial effluents tinted with trace metals pose a severe threat to biota that come in contact with it. The present investigation was carried out to study the acute toxicity of composite industrial effluent on zooplankton taking Moina sp. as indicator species. Physicochemical characterization of the industrial effluent revealed a high level of dissolved and suspended solids along with the presence of trace metals like Cr, Mn, Cu, Fe, Zn, and Pb. Toxicological investigation revealed an LC50 value of 0.92% for composite industrial effluent against Moina sp. for a duration of 24 hours exposure. These findings are important with respect to toxicological studies involving composite industrial effluent.*

Key Words: *Acute toxicity, industrial effluent, lethal concentration, urbanization, zooplankton.*

1. INTRODUCTION

The advancement of human civilization has resulted in the construction of colossal cities with all the services and amenities of the modern world for a comfortable and luxurious lifestyle for the economically privileged sect of society. However, this modernization in the form of urbanization and industrialization has brought a hidden cost to it. Both in developed and in developing countries this advancement has immensely perturbed the natural environment and as a consequence, almost all corners of the globe are facing major threats of pollution. Industrial effluent is a waste product generated by the manufacturing industry. The environmental impacts of industrial effluent have become a serious concern for human health and ecology. The most common chemicals found in industrial effluent are heavy metals such as mercury, lead, cadmium, and chromium. Composite industrial effluents tinted with heavy metals are of prime environmental concern, especially for the biotic components that interact with the contaminated aquatic environment (Chattopadhyay et al. 2002).

East Kolkata Wetland (EKW) ecosystem covers around 12,500 ha area and receives a composite mixture of wastewater (estimated to be 900 million liters per day) from almost 6000 large- and small-scale industries including tanneries along with domestic sewage. This wastewater traverses through the wetland for a span of almost 40 Km before being released into the Kultigong River. This wastewater has been utilized in pisciculture (nearly 20,000 metric tonnes of fish produced annually) and agriculture (including 4700 ha of paddy lands) and provides livelihood to more than 50,000 people (Chaudhuri et al. 2012, EKWMA and WISA 2021). However, this composite effluent carries the risk of elemental contamination and researchers have reported different element concentrations in different biota thriving in EKW (Chattopadhyay et al. 2002). Wetlands are known as kidneys of nature and it has been reported that wastewater gets progressively purified as it travels through the EKW ecosystem (Roy et al. 2013a). Since substantial volume of industrial effluents that travels through the EKW ecosystem is nearly untreated raw effluent, it is absolutely necessary to carry out toxicological studies with these effluents collected near the source point. One such industry which has the potential to cause much damage inside the EKW ecosystem is the tannery industry. Tannery effluent is very toxic and can cause harm to living organisms. The tannery effluent contains a number of chemicals, including chromium and sulfides, that are harmful to the environment. Tannery effluent is primarily discharged into open drains, which eventually reach the river. Previous studies with raw tannery effluent have shown its potential toxic influence on fish species from the present study location (Aich et al. 2010, Roy et al. 2013b).

The adverse effect of composite industrial effluent on zooplankton is on record (Cooman et al. 2003). Zooplankton *Moina* sp. is important in the aquatic ecosystem. It plays a vital role by assisting in nutrient cycling, supplying food for numerous species of fish and other animals higher up the food chain, and serving as an appropriate bioindicator. In terms of being an indicator organism: its presence or absence can be used to monitor certain aspects of water quality within lakes or ponds such as pH, temperature fluctuation, conductivity levels, and turbidity which will affect how long they can tolerate living conditions without adversely affecting their health. The present investigation was carried out with the objective of determining the acute toxicity of composite industrial effluent using *Moina* sp. as an experimental zooplankton model.

2. MATERIALS AND METHODS

2.1. Study Location and Sample Collection

The collection of composite industrial effluent was made from a stormwater flow canal (22º32′26.32″ N; 88º24′18.83″ E, elevation 4.0 m MSL) inside East Kolkata Wetland (Fig. 1). The source was within 1 Km of tannery effluent discharge site that mixed with effluents from electroplating units, pigment manufacturing units, and battery industries to name a few. Altogether, this effluent could be considered as a composite effluent discharged directly into wastewater-carrying canals inside EKWs. Collections of effluent were made for physicochemical analysis as well as toxicological studies. Three such samples were collected and values obtained for different physicochemical parameters were averaged to get the final results. The effluent was collected in clean stopper glass bottles (1 L) by immersing them completely into the water (about 10 – 12 cm below the surface of the water.

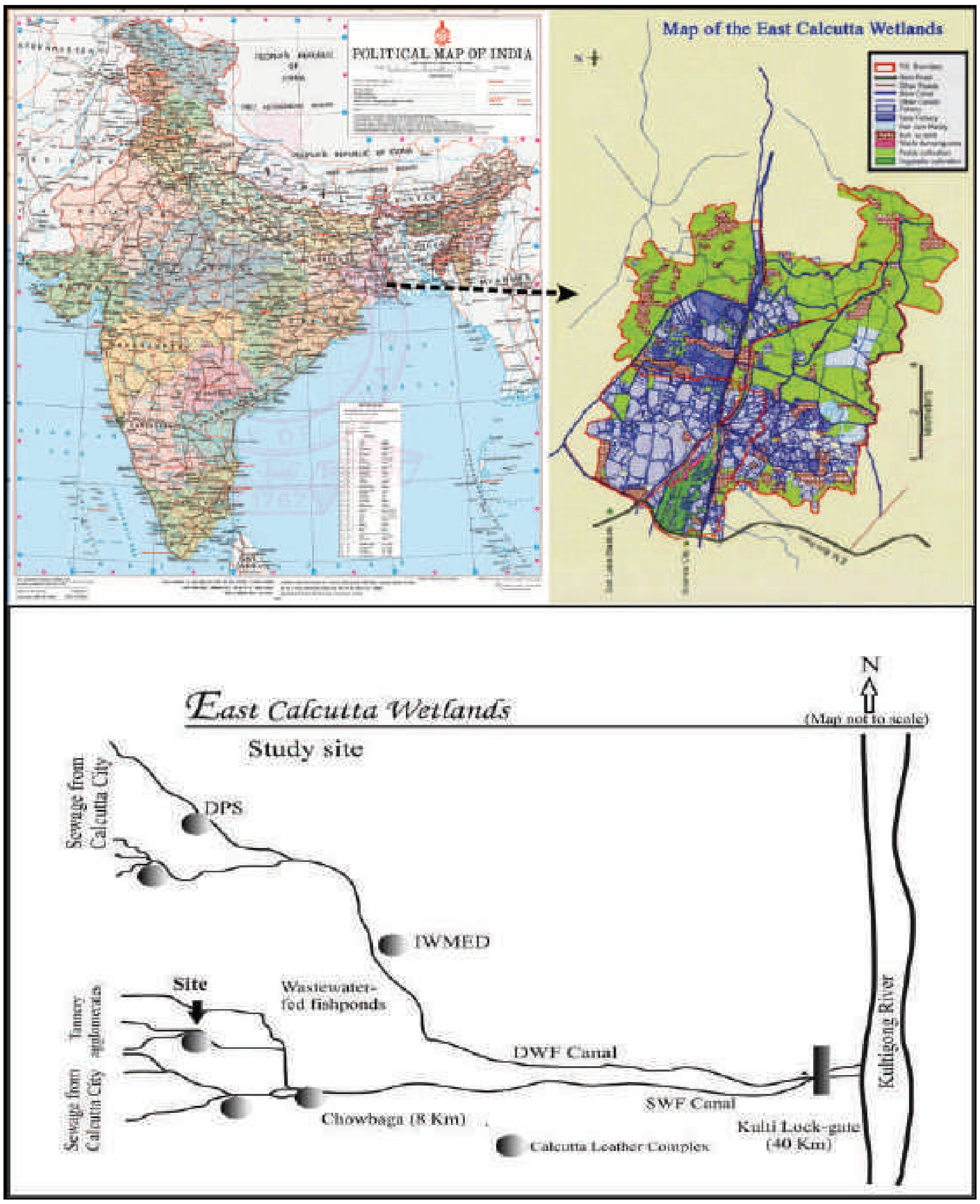

Fig. 1: *Diagram showing the location of East Kolkata Wetlands along with wastewater carrying canals and collection site of composite effluent for the present study. Source of political map of India: https://surveyofindia.gov.in/documents/polmap-eng-11012021.jpg*

2.2. Physicochemical Characterization and Elemental Analysis of Tannery Effluent

Physicochemical factors of composite industrial effluent were measured to assess some of the factors that were concerned with the inorganic constituents, like metals in the water. pH and total dissolved solids (TDS) were measured potentiometrically on the site using Multiline P4 (WTW, Germany); dissolved oxygen (DO), NO_3^-, Cl^-, Total Hardness, Carbonate Hardness, Alkalinity (determined by direct titration with standard HCl against a mixed indicator which changes its color sharply at pH 4.3 and recorded as positive m value) and Acidity (determined by direct titration with standard NaOH, the negative p-value with phenolphthalein, which changes color sharply at pH 8.2) were analyzed on the site using E. Merck, Germany, Field Testing Aquamerck reagent kits. After determinations, collected samples were acidified by 1N HNO_3 Analytical Reagent (AR) at pH 2.50 and were brought to the laboratory in 500 mL glass stopper dark bottles for immediate analysis and digestion. Total Suspended Solids (TSS) was analyzed gravimetrically following Standard Methods (APHA et al., 2005). All gravimetric analyses, reagents, and standard preparations were made using Mettler AE 240 monopan electronic balance. Detection of Cr, Mn, Fe, Cu, Zn, and Pb was done by Atomic Absorption Spectrophotometer (Perkin–Elmer AAnalyst–100 with interfacing AAWinlab Software), using element–specific hollow cathode lamps in default condition, by flame absorption mode. Standards suggested by Perkin Elmer were used for both scrutinizing the sensitivity of the instrument and calibration. All reagents used were of analytical reagent grades (Merck). The selection of elements for the study was carried out according to the major elements that are released with the effluent in different industrial processes in and around the concerned area of the EKW and contaminate the area as per the previous reports (Chattopadhyay et al. 2002).

2.3. Experimental Setup for Toxicity Test

Crustacean zooplankton *Moina* sp. (Fig. 2) was collected from uncontaminated ponds (almost 20 Km away from the polluted EKW site) and stabilized in the laboratory condition for 48 hours before being exposed to composite industrial effluent. Dechlorinated tap water was used to dilute the composite industrial effluent to 9 different concentrations of 0.125%, 0.25%, 0.5%, 1%, 2%, 5%, 10%, 15%, and 20% into 1L glass jars. 12 each of adult *Moina* sp. were released into each jar. Dechlorinated water devoid of any pollutant was used as control and 12 adult *Moina* sp. were released into a 1L glass jar that played the role of the control sample. A total of three replicates of the sample and control were set up at room temperature (34±2 ^{0}C). The next day (after a gap of 24 hours) mortality in zooplankton samples was noted and the average of the three replicates across different concentrations of composite industrial effluent was subjected to probit analysis for calculating LC_{50} value. Zooplankton in each jar was considered dead if it settled at the bottom of the jar and didn't respond when touched by a needle. No food was supplied to the jars during the toxicological studies.

Fig. 2: *Moina sp. collected from uncontaminated ponds for toxicological studies.*

3. RESULTS AND DISCUSSION

A number of water analyses of industrial effluents are regularly conducted by different groups of limnologists across the country. Chemical compositions are the most important arena in characterizing water quality. Biological, physical, and radiological factors are also considered when discussing water quality. The physicochemical condition of composite industrial effluent in the present study showed every sign of intense pollution and has been presented in Table 1.

The composite industrial effluent was blackish in colour and had a very pungent smell. It showed an alkaline pH (7.65±0.49) chiefly due to the excessive use of lime in the tanning industry. The prescribed limit for dissolved oxygen in potable water is >5.00 mg/L (WHO, 2011). However, in the present study, the composite industrial effluent was almost devoid of dissolved oxygen (0.05±0.01 mg/L) due to the huge organic material load. Again, the composite nature of the industrial effluent actually attributed to this very low oxygen concentration. Shaibu and Audu (2019) have reported much higher dissolved oxygen values from the Sharada and Challawa Industrial Areas of Kano State, Nigeria. However, high concentrations of total and suspended solids were noted in the present study (6342.43±1278.34 mg/L and 1475.51±347.86 mg/L respectively) than that of Shaibu and Audu (2019). Chloride (3882.64±761.57 mg L –1) and total hardness (1272.14±246.21 mg L –1) were also noted in very high concentrations. These values were found to be higher than those recorded by Lal (2009) in the tannery effluent from Jajmau, Kanpur, Uttar Pradesh, India.

Table 1: Physicochemical conditions of composite industrial effluent, collected from wastewater carrying canal inside East Kolkata Wetlands, values given as Mean±SD (n = 3).

Parameters	**Values**
Air temperature (ºC)	34.48±1.26
Water temperature (ºC)	32.66±2.53
pH	7.65±0.49
Dissolved oxygen (mg L^{-1})	0.05±0.01
Total dissolved solid (mg L^{-1})	6342.43±1278.34
Conductivity (mS)	12.46±2.05
Total suspended solid (mg L^{-1})	1475.51±347.86
Acidity (mmol L^{-1})	11.42±7.61
Alkalinity (mmol L^{-1})	33.64±12.47
Total hardness (mg L^{-1})	1272.14±246.21
Chloride (mg L^{-1})	3882.64±761.57
Phosphate (mg L^{-1})	2.87±0.68
Nitrate (mg L^{-1})	35.24±16.48
Nitrite (mg L^{-1})	5.53±1.82
Sulphide (mg L^{-1})	136.45±53.78
Chromium (mg L^{-1})	0.78±0.29
Manganese (mg L^{-1})	1.64±0.38
Iron (mg L^{-1})	5.23±0.73
Cupper (mg L^{-1})	0.87±0.44
Zinc (mg L^{-1})	0.45±0.12
Lead (mg L^{-1})	0.72±0.28

Study of trace metal concentration in the composite industrial wastewater showed the presence of all six metals viz. Cr, Pb, Zn, Cu, Mn, and Fe (Table 1). Sharma et al. (1996) have reported Cr concentrations as much as 5.50 mg L^{-1} in tannery effluent which was much higher than that of the present finding of Cr concentration of 0.78±0.29 mg L^{-1}. Again, the present values were within the permissible limit of 2.0 mg L^{-1} for inland surface water in India (CPCB, 1997). Among the rest of the five trace metals Zn, Cu, and Mn were all recorded to be below the prescribed concentration limits of 5.0 mg L^{-1}, 3.0 mg L^{-1} and 2.0 mg L^{-1} respectively (CPCB, 1997). It was important to note that the composite wastewater contained 5.23±0.73 mg L^{-1} of Fe and 0.72±0.28 mg L^{-1} of Pb both of which were higher than the recommended limits of 3.0 mg L^{-1} and 0.10 mg L^{-1} respectively (CPCB, 1997). The present findings corroborate well with the findings previously made from this area (Aich et al. 2010, Roy et al. 2013a, Roy et al 2013b). Industrial effluent, or the waste materials found in wastewater from factories and plants, can have a severe impact on zooplankton that play an important role in their ecosystems. Studies conducted around the globe have shown that pollutants of composite industrial effluents are causing major ecological disturbances to these vital organisms and threatening their populations (Krupa et al. 2022). The toxic elements often perturb the natural pH of the water and a change in acidification can weaken the exoskeletal structures of planktonic crustaceans making them not only prone to mortality but reproductive failures too leading further reduction in population numbers within impacted areas (Siegel et al 2022). Though it may be quite difficult to pinpoint an exact cause-effect relationship between contaminants released by industry operations and its resultant changes in behaviour and biology of aquatic life, yet varieties of indirect evidence gathered through extensive field researches have indicated potential associations between influxes of particular nutrients or other discharges & subsequent suboptimal growth patterns in certain segments of zooplankton populations (Mukhopadhyay et al. 2007).

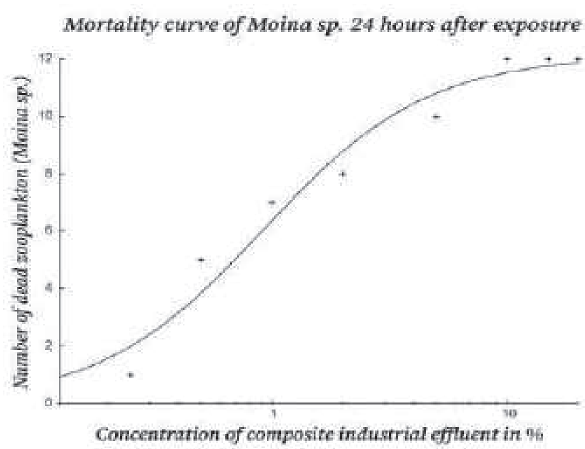

Fig. 3: *Graph depicting the mortality of Moina sp. exposed in different concentrations of composite industrial effluent for 24 hours duration.*

Research has documented adverse effects across zooplankton species such as copepods, rotifers, cladocerans, and ostracods due to pollution from industries ranging from pulp and paper mills to soaps which contain harmful chemicals discharged into water bodies without proper treatment methods being utilised (Mishra and Pande 2020). Researchers around the globe have found that pollutants from industry adversely affect zooplankton populations by having detrimental effects on their development, feeding behaviour, mortality rates, reproductive capacity, and temperature sensitivity rate (Uriarte and Villate 2004). There have been a number of studies done on the LC_{50} (the concentration of a toxicant that kills 50% of the population) of zooplankton with industrial effluent. These studies show that industrial effluents can significantly reduce the abundance and diversity of aquatic species due to their toxicity. In the present investigation composite industrial effluent was found to be highly toxic for zooplankton species *Moina* (Fig. 3). The LC_{50} value for *Moina* sp. against composite industrial effluent was recorded as 0.92% in the present study. This finding corroborates well with that of Cooman et al (2003) who have studied the toxicity of tannery effluent on *Daphnia pulex* and *Daphnia magna* and found that LC_{50} values ranged between 0.36% to 3.61% for 24 hours of exposure time.

Zooplankton *Moina* sp. responds quickly to changes in water quality, making it useful for assessing overall water health status. Its sensitivity allows researchers to use them as indicators of organic pollution and heavy metal contamination levels in aquatic systems and this was also evidenced in the present study. The high levels of contaminants present in composite industrial effluents such as heavy metals and organic pollutants caused the toxicity to zooplankton species *Moina* in the present study. Also, the presence of organic chemicals like surfactants, dyes and other substances that affect pH balance and chemical composition played a significant role in the mortality of zooplankton in industrial effluent during the present study.

4. CONCLUSION

Composite industrial effluent discharged inside EKWs was found to be polluted enough to cause acute toxicity to *Moina* sp. Though a few physicochemical parameters of water were within the permissible limit, others were far beyond recommended limits. Hence, it is absolutely necessary to monitor the situation for quick remediation. This may include limiting wastewater discharges by improving process management. Production processes should be managed effectively in order to limit wastewater output and improve its quality before entering the environment. Improving waste treatment systems by removing or reducing toxicants before being released into nature can be effective. Better technologies, chemicals, and biocatalysts could help industries optimize their processes while at the same time minimizing the release of pollutants. This is to be hoped that proper implementation of laws along with the scientific management plan will be beneficial in reducing toxic loads and thereby sustain East Kolkata Wetland Ecosystems with its fullest potential for a longer time period.

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6. REFERENCES

Aich A., Chattopadhyay B., Datta S. and Mukhopadhyay S.K. (2010). "Impact of composite tannery effluent on the amino-transferase activities in a fish biosystem, using Guppy fish (*Poecilia reticulata*) as an experimental model." *Toxicological and Environmental Chemistry*, 93: 85-91.

APHA. (2005). "Standard Methods for Examination of Water and Wastewater." *American Public Health Association*.

Chattopadhyay B., Chatterjee A. and Mukhopadhyay S.K. (2002). "Bioaccumulation of metals in the East Calcutta Wetland ecosystem." *Aquatic Ecosystem Health & Management*, 5: 191–203.

Chaudhuri S.R., Mukherjee I., Ghosh D. and Thakur A.R. (2012). "East Kolkata Wetland: a multifunctional niche of international importance." *Online Journal of Biological Sciences*, 12(2): 80–88.

Cooman K., Gajardo M., Nieto J., Bornhardt C. and Vidal G. (2003). "Tannery wastewater characterization and toxicity effects on *Daphnia spp*." *Environmental Toxicology*, 18: 45-51.

CPCB - Central Pollution Control Board. (1997). "*Parivesh, World Environment Day Issue*", New Delhi.

EKWMA and WISA (2021). "East Kolkata Wetlands: Management Action Plan 2021 – 2026." *East Kolkata Wetlands Management Authority and Wetlands International South Asia.*

Krupa E., Aubakirova M. and Romanova S. (2022). "Factors affecting water quality and the structure of zooplankton communities in wastewater reservoirs of the right-bank Sorbulak Canal System (South-Eastern Kazakhstan)." *Water*, 14(11):1784. https://doi.org/10.3390/w14111784

Lal N. (2009). "Biochemical alterations due to acute tannery effluent toxicity in *Lemna minor* L." *Journal of Phytology*, 1: 361-368.

Mishra A. and Pande R.K. (2020). "The effect of pulp and paper industry effluent on the biological and bacteriological parameters of River Hindon." *International Journal of Scientific Study*, 8(5):110-113.

Mukhopadhyay S.K., Chattopadhyay B., Goswami A.R. and Chatterjee A. (2007). "Spatial variations in zooplankton diversity in waters contaminated with composite effluents." *Journal of Limnology*, 66(2): 97–106. https://doi.org/10.4081/jlimnol.2007.97

Shaibu A.N. and Audu A.A. (2019). "Evaluation of physiochemical parameters and some heavy metals from tannery effluents of Sharada and Challawa industrial areas of Kano State, Nigeria." *Nigerian Journal of Basic and Applied Science*, 27(2): 162-171. http://dx.doi.org/10.4314/njbas.v27i2.22

Sharma D.C., Srivastava P.C., Johri B.N. and Chandra P. (1996). "Environmental impact of tannery effluents on heavy metal phytotoxicity and health hazards." *Journal of Industrial Pollution & Contamination*, 12: 137-142.

Siegel KR., Kaur M., Grigal A.C., Metzler R.A. and Dickinson G.H. (2022). "Meta-analysis suggests negative, but pCO_2-specific, effects of ocean acidification on the structural and functional properties of crustacean biomaterials." *Ecology and Evolution*, 12: e8922. https://doi.org/10.1002/ece3.8922

Roy U.S., Goswami A.R., Aich A., Chattopadhyay B., Datta S. and Mukhopadhyay S.K. (2013a). "Changes in physicochemical characteristics of wastewater carrying canals after relocation of Calcutta tannery agglomerates within the East Calcutta Wetland ecosystem (a Ramsar site)." *International Journal of Environmental Studies*, 70(2): 203–221.

Roy U.S., Aich A., Chattopadhyay B., Datta S. and Mukhopadhyay S.K. (2013b). "Studies on the toxicity of composite tannery effluent using guppy (*Poecilia reticulata*) as a fish model." *Environmental Engineering and Management Journal*, 13(3): 557–563.

Uriarte I. and Villate F. (2004). "Effects of pollution on zooplankton abundance and distribution in two estuaries of the Basque coast (Bay of Biscay)." *Marine Pollution Bulletin*, 49(3): 220-228.

WHO. (2011). "Guidelines for drinking-water quality." *4th Edn. WHO Press*, *World Health Organization*, Geneva 27, Switzerland.

Assessing the Tsunami Hazards on the Western Coast of India: A Systematic Review

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Abstract: *The Consequences of natural calamities like Tsunami results in huge amount of economic and ecological loss. If the nature and intensity of the hazard is severe and affected region is densely populated then number of casualties will be also inevitable. Tsunami arises out of vertical movement of submarine plates of the earth. Makran Tsunami which struck the coast of Makran on 27th November 1945 resulted in casualties exceeding number of 4000. Makran zone Tsunami has critical effect on western coast of India and in present context, there are number of developments on Gujarat coastal belt which lies on the western part of India which is approximately 1600 Km. long. From socio-economic point of view important ports/jetties, refineries, chemical industries, and salt processing unit present there has very much economic impact on Gujarat coastal belt which makes it crucial for hazard assessment. This paper reviews and summarizes the deterministic and probabilistic approach for hazard assessment and results of same are presented. From Makran subduction zone probability of hitting tsunami of wave height more than 5 meter is 17.5% in next fifty years and for moderate tsunami there is probability of 45%. Inundation mapping for Gujrat Coastal belt shows that there are chances of Inundation for Banni region with higher amplitude waves and desert of Kutch can be inundated with lower elevation waves.*

Key Words: *Impact of Tsunami, Tsunami risk assessment, Deterministic Approach, Probabilistic Approach.*

1. INTRODUCTION

Tsunami is one of the deadly hazards causing social and economic disruptions, loss of life and livelihood along the coastal belt. The social and economic disruption created aftermath of Tsunami is inevitable. Most affected region due to earthquake generated tsunamis are northern tip of Bay of Bengal, Makran coasts of Iran and Pakistan, Western region of Andaman Sea which also skirts the southern portion of java, Sumatra, lesser sunda Islands. These tracts underlain geologically underlain Makran and Sunda subduction zone (Rose Enid Teresa et al. 2020). On November 28, 1945, at 03:26 IST tsunami occurred in Arabian Sea which was one of the most devastating natural hazards causing severe casualties. The great earthquake of MW 8.0 which was located at 25.204_N 63.420_E in the northern Arabian sea about 100 Km south of Karachi and 87 Km SSW of Churi, Pakistan caused this tsunami. The height of the tsunami on some of the Makran Ports was reportedly as high as 12 meter which resulted in vast devastation on the entire coastal region of Makran (Pararas-Carayannis 2006).

The impact of Makran was observed in Muscat and Gwadar also. The waves of height of 1.5-meter, 2 meter and 0.5 meter was observed at Karachi, Mumbai, and Seychelles, respectively. The waves of height of 11.0 to 11.5 meters were noticed on the dry coast in Kutch of Gujarat (C.G. Pendse 1946). The first recorded wave was at 5:30 am and then subsequently at 7:00 am, 7:15 am and then the last and biggest recorded wave at 8:15 am. The last wave was observed in Mumbai. In Mumbai at Bombay Harbour, Versova, Haji Ali, Juhu, and Khar was the affected areas. Overall wave of height of 2 meter was observed in Mumbai causing 15 deaths (Rastogi & Jaiswal 2006). Prediction of Earthquake is not possible, but after detection of earthquake there is few minutes to few hours of time for noticing the potential tsunami that can take place on coastal region due to the earthquake detected. The time available for predicting the tsunami is dependent on the closeness of the epicentre to coastal region. Damages due tsunami can be mitigated by early warning systems. West Coast of India is mainly affected by the Makran subduction zone of Arabian Sea and proper simulation of those waves can be of great help for preparedness and mitigation of tsunami (Jaiswal et al. 2009).

2. **GEOLOGY AND CHARACTERISTICS OF MAKRAN SUBDUCTION ZONE**

Tsunami is generated by earthquakes which is due to movement of the tectonic plates underneath the earth crust. Subduction zone is created along the Makran coast of the Pakistan due to the combined movement of Indian, Arabian, and Iranian plates. One of the largest sedimentary accreted wedges covered with 7 Km of thick sediments is Makran subduction zone. Makran subduction zone which is 1200 Km long between boundary of Iran and Pakistan is not seismically active as Himalaya and Sunda Arc but it has past records of generating large earthquakes and tsunamis (Jaiswal et al. 2009). It is noted in the literature that every year there is 4 cm of northward convergence of Arabian plate into Makran Subduction zone (Demets et al., 1990). There are four different rupture segments of length about 200 km each in the plate boundary which is caused by five large historical earthquakes of 1483, 1851, 1864, 1945 and 1765 in Makran (Byrne et al. 1992).

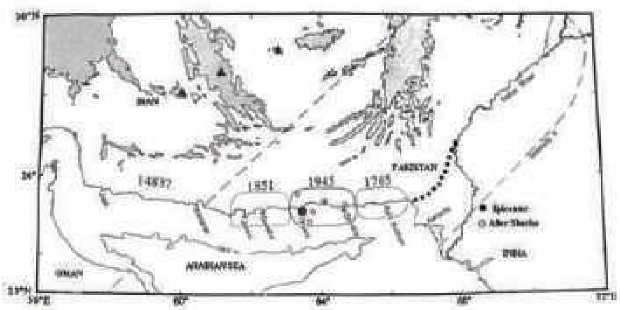

Fig. 1: Historical great earthquakes of Makran Subduction Zone (Byrne et al. 1992)

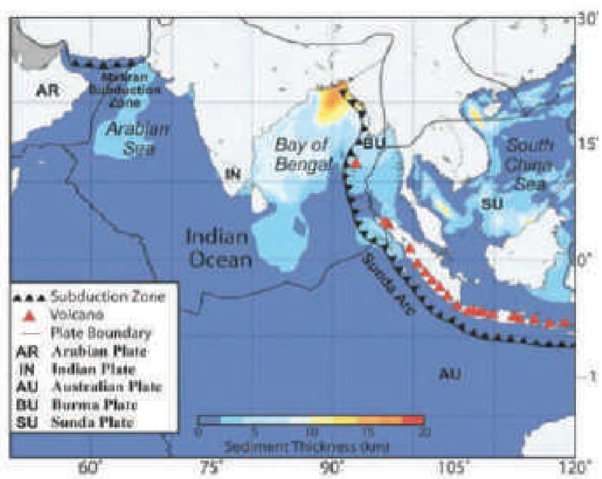

Fig. 2: Subduction Zones and Major plates

(Source: Geoscience Australia) (Arthurton & Russell (ed.) 2009; UNESCO-IOC 2015)

The easternmost Makran (Karachi) has strongly felt the earthquake of 1765. The earthquake events of 1851 and 1864 has affected the eastern Makran town Gwadar (Quittmeyer 1979). Among all the large historical earthquakes of Makran subduction zone noted previously, 1945 earthquake has generated a large tsunami. Eastern Makran of Pasni was struck by this earthquake and the following aftershock was observed in 1947 in the south. Table 1 below lists the earthquakes having effect on the Indian West coast and its region in its proximity. Oldest tsunamis record available is from 326 BC, November which caused the huge sea wave generation in the Arabian Sea (Rastogi & Jaiswal 2006). There is no clear evidence recorded for great earthquakes in West Makran zone but an earthquake which was recorded on 1483 has affected northeast Oman and Strait of Hormuz which gives sign of occurrence of earthquake somewhere in Western Makran, but there is no information available for exact location. Holocene terraces present along the portions of eastern and western Makran are evidence that sections of both the arc can generate large plate boundary movements (Byrne et al. 1992).

2.2 Sources Zone of Delta of Indus, Karachi, Kutch-Saurashtra and Omen Fault Regions

The lateral transition between Subduction and collision of Indian and Arabian plates tectonic plates have made source zone in Kutch, Cambay, Bombay and Namacia Graben in north-western India. There is potential of generating local tsunamis on west coast of Maharashtra due to earthquakes associated with subsidence faulting and thrust in the Kutch Graben and major fault running along the west coast of Maharashtra (Pararas-Carayannis 2007). There is also potential of tsunami in the Saurashtra -Kutch region in the west of India due to thrust type earthquake occurring along the coastal zone of compressive stress along Indus Delta (Pararas-Carayannis 2007; Rastogi & Jaiswal 2006). Figure 3 shows the tectonic map of Saurashtra, Kutch western part of India which shows the offshore and coastal faults along the coastal belt of Maharashtra, Kutch, and Saurashtra.

3. IMPACT OF TSUNAMI

When there is occurrence of plate movements beneath the surface of ocean, submarine earthquake will be generated and it will shake the surface under ocean which will create huge water waves and this water wave possesses huge amount of energy and when this wave propagates towards the coast it will create massive destruction and casualties. The assessment of the casualties and damage of infrastructure and built environment is necessary to get an idea about the losses incurred due to the disaster. Impact of any disaster can be categorised as Tangible and Intangible effect and Direct and indirect effect (Bureau of Transport Economics 2001; Mex 2003; Smith 2009). Tangible effects are those which is physically sensible or one which is measurable in terms of monetary aspect like damages to the structures and installations and other physical things and that damages are caused by the high energy tsunami waves which has invaded the coastal belt and region in its proximity. When tangible effect is relatable to direct effect which refers to the impact caused due to invasion of the waves on the coast and its vicinity. The damage to buildings, infrastructure, and other installation due to the collision of huge energy waves is known as direct effect. The consequences arising after tsunami which is economic loss due to damage occurred during tsunami is categorised as indirect effect. Indirect effect also accounts the disruption in the life due to damage of necessary livelihood things. Again, here indirect effect and intangible effect are relatable as all the consequent events and its effect like loss to health, mental trauma and all the damages which is not measurable in terms of monetary aspect is accounted as intangible effect. Further the effect of tsunami can also be categorised as primary and secondary effect. When the high energy waves collide with the structures and the effect which it creates is considered as primary effect. Once the wave of tsunami settles but the consequent effects which are there due to damages such debris, contamination of water, leakage of fuel from oil storage stations and fire and explosions and other similar effects arising due to primary effect are considered as secondary effect (Yalciner et al. 2011).

Table 1: History of Tsunamis affecting Indian West Coast and Vicinity

References	Date	Location	Impacts
(Lisitzin Eugenie 1974)	326 BC	Indus Delta/ Kutch Region	Disastrous consequences on Macedonian fleet.
(Murty et al. 1999)	1008	Iranian Coast	Tsunami in North Indian Ocean due to Local earthquake
(Bendick et al. 1999)	1524	Dabhol, Maharashtra, India	-
(Oldham 1883)	May 1668	Samaji- Indus Delta	The samaji town with 30000 houses sunk into ground.
(Macmurdo C 1821)	16/08/1819	Kutch	Sindri town sink by 5 meters due to inundation
(Nelson C, 1846)	19/06/1845	Kutch	-
(Murty et al. 1999)	28/11/1945	Makran Coast	Death recorded exceeds number of 4000 on Makran Coast and is caused 15 deaths in Mumbai. Max. run up was of 17 m and average wave height in Mumbai was 2 m. In Kutch, wave height of 11 to 11.5 m was recorded (C.G. Pendse 1946)

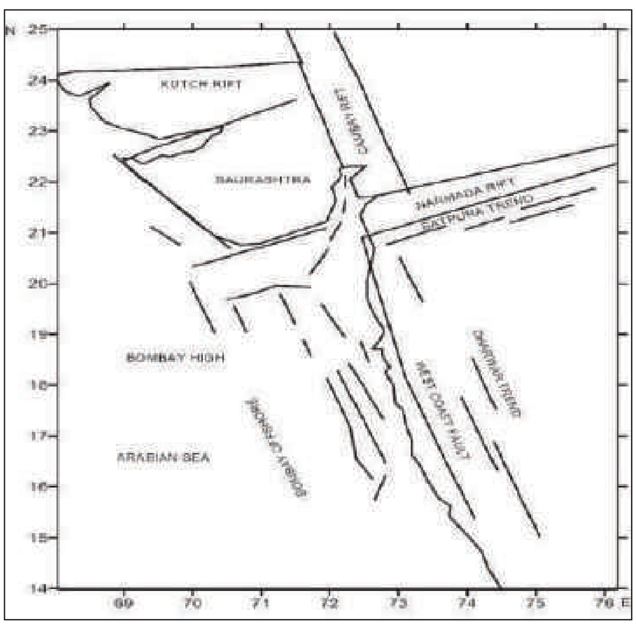

Fig. 3: *Tectonic map of Indian West Coast (Jaiswal et al. 2007)*

3.1 Tsunami Damages and Casualties

Generally, while examining the tsunami damages and casualties, four factors mentioned below play a major role (Berryman 2005). Potential damages that can occur due to tsunami are categorised in tabular form in Table 2:-

1. Torrents and Bores: swiftly flowing torrents with speed up to 40km/hr, or bores (water with increasing heights having step like increase) cause soil erosion at sea floor and coast. Also, the receding wave causes severe casualties because they are main cause of drowning which sweeps people to the sea.
2. Debris Impacts: The remaining of damaged building and heavy structures flowing through the inundation and receding wave can cause severe harms to the life.
3. Fire and Explosions: When the high energy waves rush from the ocean it destructs the infrastructure and there will be damage to electricity line, fuels leakage will be there which has very high potential of fire and in turn this fire as a secondary effect will cause severe casualties.

4. Inundation and Contamination: When the sea water rush towards the coastal region, all the sources of water in its vicinity gets contaminated and there will be very high chances of spreading epidemic and harm to living creatures.

Table 2: Potential Damages and Casualties that can be caused by Tsunami (Berryman 2005)

Affected Areas	Effect of Damages
People and Animals	Drowning
	Injury caused by Debris and impact of flowing structures
	Sand blasting effect creating skin wounds due to suspended particles
	Injury and Illness due to contamination and spread of epidemic.
Built Environment	Damaged buildings due to collision of high energy tsunami waves.
	Obstruction of Sewage lines
	Oil spills from vehicles, and damaged industrial structures.
Natural Resources	Soil Erosion and deposition
	Pollution due to leakage of chemicals, oils, and gases from the damaged industrial structures in coastal areas
	Contamination due to sewage
	Snapping and uprooting of trees
Coastal Activities	Littering of shipping lanes
	Damages to boats and ships
	Displacement of Buoys
	Alteration of Channels due to deposition of debris
	Destruction of Ports and Jetties

Table 3: Summary of Scenario based and Probabilistic Hazard Assessment Method

Scenario Based	Probabilistic
It is deterministic Approcah considering the past data and creating the scenario in mordern context based on historical evidence.	This method is in early development stage and is in close alliance with the porbabilistic sesimic hazard assessment.
These scenarios are taken and worst possible case or most likely possible case of tsunami event is included from the historical evidence.	It considers wide range of scenarios which causes the significant impact and is based on more than one geological framework.
It is the simplest method to understand potential impact of tsunami and specifically to demonstrate the worst possible case.	All the possible future events are considered and the sixe, frequency and intensity of all the sources are examined.
Inundation modelling may or may not be there in STHA	This method focusses on the likelihood that a tsunami of a given height at the study site will be exceeded.
Reliability of STHA is limited to address the potential impact of the case based on different scenarios or combination of different scenarios or only a single scenario	Detailed effect of Tsunami inundation is not modelled in PTHA due to lack of bathymetric data
It needs the bathymetric and topographic information in high resolution for the interested shore.	This method struggles with the uncertainty and inherent variability of the data, hence different models are developed and proper weight is assigned to them with expert judgment and results of this model are used.

Table 4: Magnitude and Height of Tsunami waves and Potential Damage associated with it (Lisitzin Eugenie 1974)

Magnitude	Height of Tsunami Waves	Potential Damage
-1	50-70 cm	No damage
0	1-1.5 meter	Very little damage
1	2-3 meter	Shore damage
2	4-6 meter	Some inland damage and loss of life
3	8-12 meter	Severe destruction over 400 km of coast
4	16-24 meter	Severe destruction over 500 km of coast

3.2 Methodology for Risk Assessment

For planning the mitigation measures, coastal department needs the data and information about the impact of the tsunami and the potential damage which can be incurred due to the tsunami. There are two approaches that can be used for the assessment and they are Scenario based Hazard Analysis and Probabilistic Tsunami Hazard Analysis. Although these two approaches appear to be mutually incompatible but in actual, they are complimentary and combination of both gives very good understanding and serves helpful in risk assessment. Scenario based approach is more focussed on the historical evidence and their correlation with the modern context. On the other hand, probabilistic approach considers for all the future potential of the hazard and examines the size, frequency and intensity and effects of all the potential sources (UNESCO-IOC, 2009). For tsunami risk assessment there are five principal factors as listed below which has an important role in assessment (Berryman, 2005):-

1. Intensity of Tsunami generating source (Size & frequency of earthquakes, volcanoes, and landslides)
2. Propagation of Wave through water
3. In rush of water (Inundation)
4. Location and Distribution of the people, dwellings, and buildings
5. Vulnerability and fragility of the assets

As mentioned earlier, there are two methods for assessment of the risk, both methods have their advantages and limitations. Both methods are summarized in Table 3.

Potential of the damage which Tsunami can cause can be further known by the magnitude and height of the Tsunami Waves. Table 4 below shows the magnitude and height of the waves and the potential damage it can incur.

3.3 Tsunami Hazard Assessment for Indian Coast

The Makran subduction zone is one of the critical tsunamigenic zone for the Iran, Pakistan, and western coast of India. On 27th November 1945, the earthquake of magnitude 8.1 was observed in this region which caused tsunami with ran up of 5 m to 12 m and casualties of more than 4000 people. Investigation of the Makran tsunami hazard can be done using semi-probabilistic approach full probabilistic approach. In Semi-probabilistic approach the maximum wave height caused by the largest possible earthquake in the region. Largest possible earthquake is determined using probabilistic seismic hazard assessment method. Largest expected earthquake determined using PSHA method is of moment magnitude 8.3 with the recurrence period of 1000 years. Tsunami which can be generated by the earthquake of 8.3 moment magnitude can reach the maximum run up height of 9.6 meters along the coast of Makran. To assess the likelihood of the tsunami impact on the Makran coast Probabilistic Tsunami Hazard Assessment was conducted. To determine the probability of the water level exceeding the given maximum water elevation at the coast of Makran, combination of the probability of an offshore earthquake occurrence with numerical modelling of tsunami is done. The results of the Makran subduction zone revealed that probability of wave height exceeding 5 meters along the coast of Makran for next 50 years is 17.5 percentage. There is probability of 45 percentage for the moderate tsunami with the wave height of 1 meter to 2 meter (Heidarzadeh et al. 2009; Heidarzadeh 2008a; Heidarzadeh, et al. 2008b; Patel et al. 2016; Velioglu Sogut & Yalciner 2019). When the hazard assessment was carried out using the deterministic approach based on method developed by Japan Society of Civil Engineers, result revealed that tsunami from the Makran region can cause damage to the West coast of India and especially to the Gujarat coastal belt as it is near to the Makran subduction zone. There are chances of Tsunami generation in the area due to landslides also, however here only earthquake is considered for the tsunami generating source as all the past evidence shows major source as earthquake in this region (Baptista et al. 2020; Heidarzadeh & Satake 2014, 2017; Rashidi et al. 2020; Rastgoftar & Soltanpour 2016). Again, when narrowed down to Gujarat coast belt, in India it is one of the longest coastal belts covering 1600 kilometres. Gujarat Coastal belt is very much important from economical as well as ecological point of view which is elaborated in next section. The plots of mean wave height have been estimated at every location of the coast at first water cell. It is observed that mean wave height at west coast is generally below 2 meters and will have lower hazard comparatively. This is because the parallelism of the coastline with the deep-sea waves. Gulf of Khambhat and northern Maharashtra have wider continental shelf (more than 100 km) which makes them less vulnerable to the tsunami hazard from Makran zone (Roshan et al. 2016). Plots of mean wave height are shown in Figure 4.

3.4 Importance of Gujarat Coastal Belt

When viewed from economical point of view coastal belt is very important as there are number of ports/jetties and industrial installations. Along Gujarat coastal belt, there are 19 active ports, oil storage stations, chemical industries, and refineries. This all installations are very much important from economic point of view. Figure 5 below shows the important ports and jetties. One of the largest and significant port with free trade is Kandla Port in the Gulf of Kutch region and has huge amount of investment. There are approximately 20 jetties which support the fishing business.

There are 21 salt units in inter-tidal region and wind farms developed on the coastal belt of the Gujarat.

When viewed from ecological perspective, sensitive flora and fauna and tourism business is also well developed in the gulf of Kutch region. When any tsunami hits the region, natural and anthropogenic features and economy of the region is directly or indirectly affected. It is worth to make note here that Makran Tsunami of 28th November 1945 has also the affected the Kandla Port but during that event Kandla was just a barren land. But if the Tsunami of same intensity hits the region in future time, the loss incurred economically and ecologically would be very huge. Along with this economic and ecological loss, the casualties resulting from the tsunami will also be inevitable. The increased focus on economic expansion at coastal belts and dynamic situation of Socio-economic conditions of coastal belt makes it crucial to study the tsunami and its potential impact to prepare the mitigation plans.

3.5 Inundation Mapping for Gujarat Coastal Belt

Gujarat state is situated on the western part of India with longest coastline of about 1600 Km and is also close to Makran subduction zone which is tsunamigenic earthquake source. Ecological and economical importance of the Gujarat coast makes inundation mapping crucial for Gujarat coast. To prepare the Inundation model for the Gujarat coastal belt, existing bathymetric and topographic datasets have been used. High resolution datasets of 3 arcs second or 90 m have been used and elevation have been plotted using the GIS software. Height of the tsunami wave also depends on the elevation plot generated by GIS. Various elevation over the Gujarat state is shown by use of the colour code such as 0-2, 2-5, 5–10 meters elevation is represented by green, pink, and dark blue colour, respectively. Figure 6 below shows the elevation plot over the Gujarat state. From the elevation plots it is noted that in Gulf of Kutch there will be more inundation because Kutch region has lower elevations (Jaiswal et al. 2009). Further, Banni region of Kutch will inundate because of high tsunami waves whereas Kutch Desert would inundate due to low tsunami waves. From the inundation mapping it is evident that some portion of southeast Porbandar and north of Bhavnagar of Saurashtra region would be affected by the higher tsunami waves. Higher amplitude Tsunami waves may also inundate the southern Gujrat coast which is from Khambhat to Navsari having important jetties and some major ports. From the results it is noted that there will be higher number of casualties due to the severe impact of the inundation in gulf of Kutch and Khambhat. In desert of Kutch there are chances of inundating up to full extent but the region is less populated so casualties will be lower (Jaiswal et al. 2009).

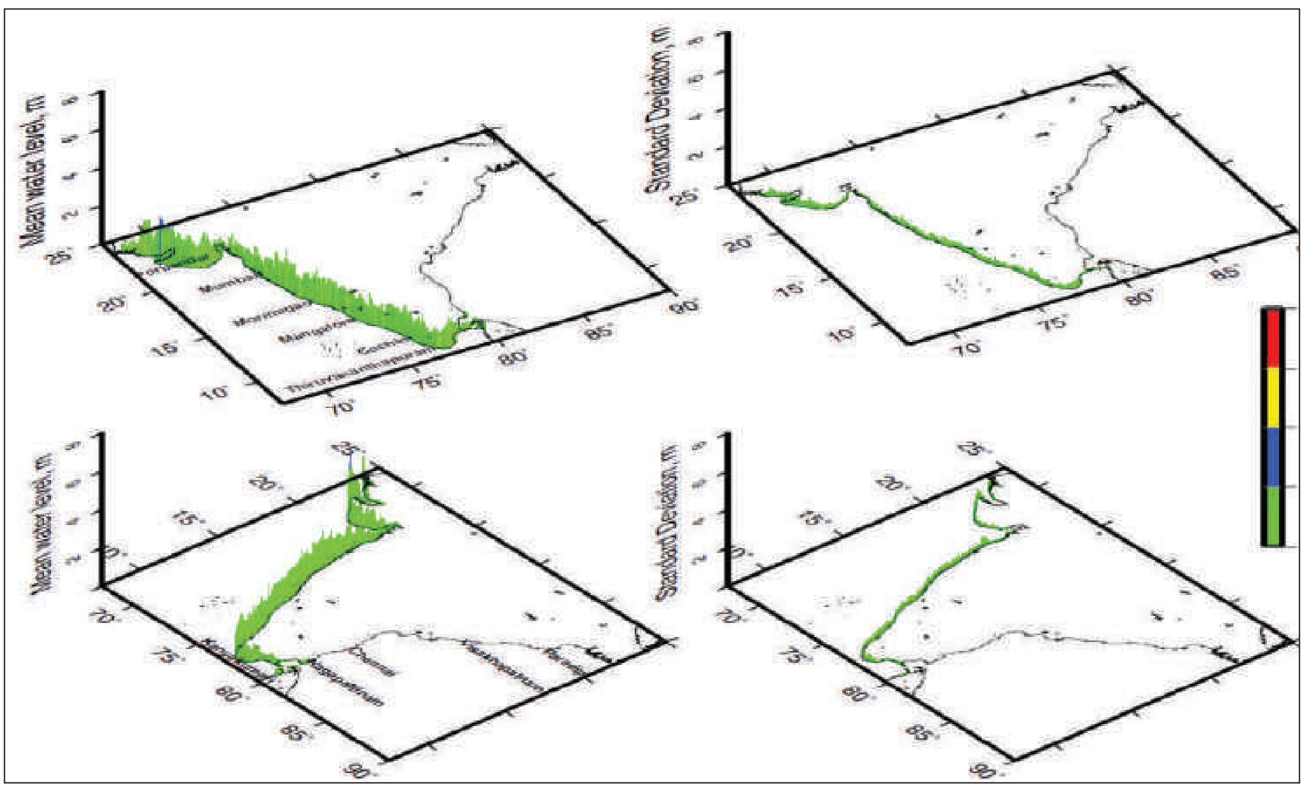

Fig. 4: *Mean Tsunami Wave height with standard deviations in water level for different scenarios generated from the Largest possible earthquake from the Makran Subduction Zone (Roshan et al. 2016*

Fig. 5: *Important Ports and Jetties along the Gujarat Coastal Belt (Singh et al. 2008)*

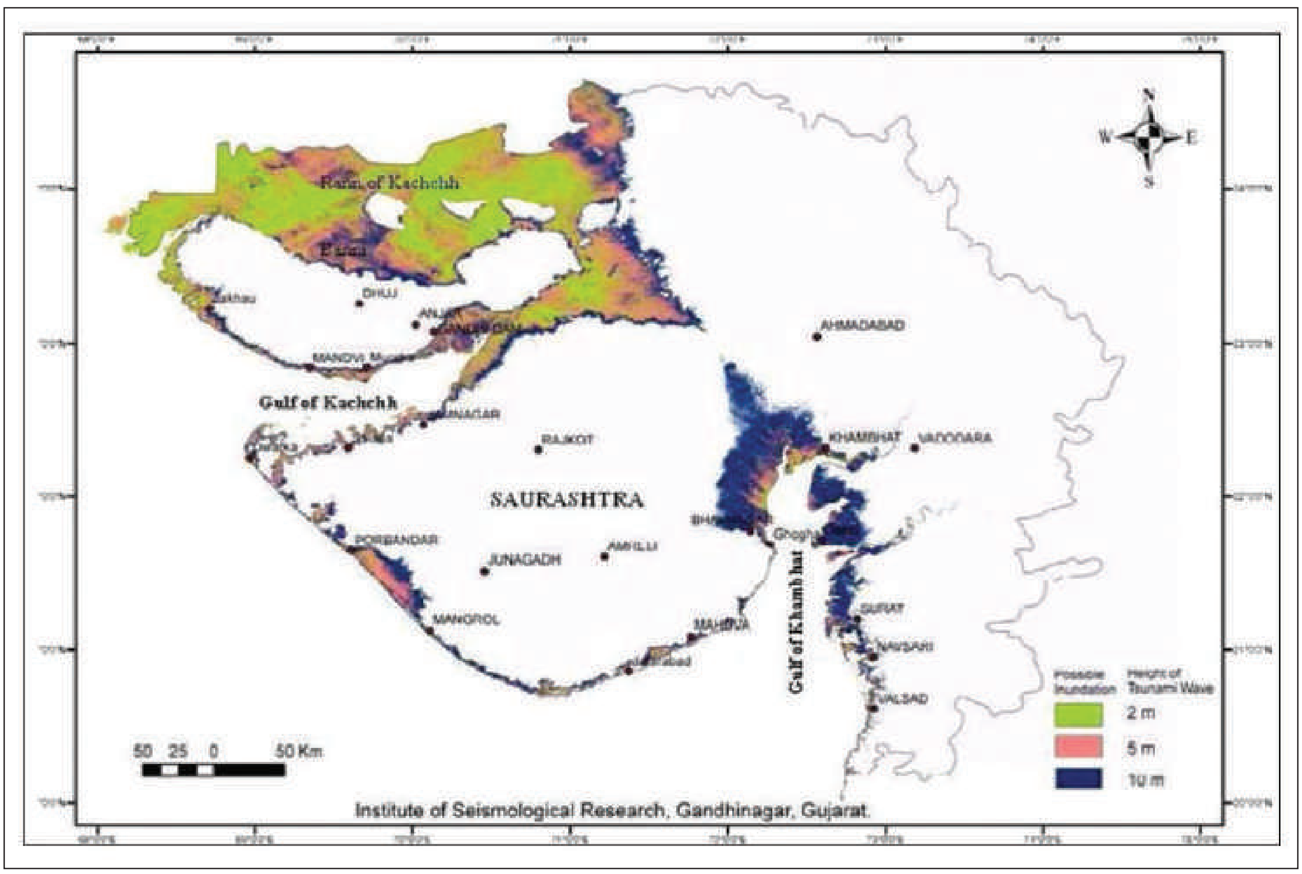

Fig. 6: Possible Inundation with different Wave Heights (Jaiswal et al. 2009)

4. CONCLUSION

From the review of the different work done in the area of Tsunami hazard assessment, we have arrived at a conclusion that Gujarat is more vulnerable to tsunami attack and particularly gulf of Kutch and Khambhat can suffer from severe losses if hit by the tsunami. Makran subduction zone which was inactive since past 30 years have shown seismic activities from November 2005 and there is enough potential of generating tsunamigenic earthquake in upcoming time. If the tsunami like 1945 hits the western coast of India the economic damage causality resulting out of it will be inevitable. To assess the potential damage and impact which can be there on the western coast of India and specifically on the Gujarat coastal belt, Tsunami hazard assessment is needed to be done and there are two different methods for assessing the tsunami hazard. One method is scenario based deterministic approach and other is probabilistic approach. Probabilistic approach showed that there will be probability of 17.5 % of generating the tsunami waves of height above 5 meters in next 50 years and for moderate tsunami with wave of height between 1-2 meters will be 45%. Assessment done with deterministic approach shows less hazard on the Gujarat coast due to its parallelism with the deep sea wave and the advantage of wider continental shelf of more than 100 Km makes gulf of Khambhat and northern Maharashtra less vulnerable to the tsunami attack. The Inundation mapping with existing bathymetric and topographic datasets of the Gujarat coast have revealed that there will be inundation in Banni region of Kutch and Saurashtra region of Gujarat due to high amplitude tsunami waves. The desert of Kutch will be inundated due to lower amplitude tsunami waves.

5. MAJOR FINDINGS AND FUTURE SCOPE

For risk assessment and tsunami hazard assessment two approaches are widely used and both the approaches have their merits and demerits. Probabilistic approach is still under development and is closely allied to Probabilistic Seismic Hazard Assessment method. For Inundation mapping and developing mitigation plans scenario-based hazard assessment or deterministic approach is more prevalent among researchers whereas to predict the likelihood of the future potential events probabilistic method is used. While estimating the wave height for the tsunami, magnitude of earthquake, topographic and bathymetric data is taken into consideration but the effect of the tides occurring during tsunami is not accounted. The estimated wave height will be lower but in actual case if tides are occurring during the tsunami even then height of wave will be higher than height estimated using the datasets.

There is need of research in estimating wave height which also considers the tidal effect. Future research scope also lies in tsunami hazard assessment using combination of both scenario based and probabilistic method for tsunami hazard assessment.

6. REFERENCES

Arthurton, & Russell (ed.). (2009). "Hazard awareness and risk mitigation in integrated coastal management (ICAM)." UNESCO-IOC, Intergovernmental Oceanographic Commission Manuals and Guides, 50, (ICAM Dossier; 5). https://doi.org/https://doi.org/10.25607/OBP-1441

Baptista, M.A., Miranda, J.M., Omira, R., & El-Hussain, I. (2020). "Study of the 24 September 2013 Oman Sea tsunami using linear shallow water inversion." *Arabian Journal of Geosciences*, 13(14). https://doi.org/10.1007/s12517-020-05632-z

Bendick, Rebecca and Bilham, & Roger. (1999). "Search for buckling of the southwest Indian coast related to Himalayan collision."

Berryman, K. (2005). "Review of Tsunami Hazard and Risk in New Zealand." https://www.civildefence.govt.nz/assets/Uploads/publications/GNS-CR2005-104-review-of-tsunami-hazard.pdf

Bureau of Transport Economics. (2001). "Economic costs of natural disasters in Australia."

Byrne, D.E., Sykes, L.R., & Davis, D.M. (1992). "Great thrust earthquakes and aseismic slip along the plate boundary of the Makran subduction zone." *Journal of Geophysical Research*, 97(B1), 449–478. https://doi.org/10.1029/91JB02165

C.G. Pendse. (1946). "The Mekran Earthquake of the 28th November 1945." Indian Meteorological Department, 125.

Demets, C., Gordon, R.G., Argus2, D.F., & Stein2, S. (1990). "Current plate motions." *In Geophys. J. Int* (Roč. 101).

Heidarzadeh, M., & Satake, K. (2014). "Possible sources of the tsunami observed in the northwestern Indian ocean following the 2013 September 24 Mw 7.7 Pakistan inland earthquake." *Geophysical Journal International*, 199(2), 752–766. https://doi.org/10.1093/gji/ggu297

Heidarzadeh, M., & Satake, K. (2017). “A combined earthquake-landslide source model for the tsunami from the 27 November 1945 Mw 8.1 Makran earthquake.” In Bulletin of the Seismological Society of America (Roč. 107, Číslo 2, s. 1033–1040). Seismological Society of America. https://doi.org/10.1785/0120160196

Heidarzadeh, M., Pirooz, M.D., Zaker, N.H., & Synolakis, C.E. (2008a). “Evaluating tsunami hazard in the Northwestern Indian Ocean.” *Pure and Applied Geophysics,* 165(11–12), 2045–2058. https://doi.org/10.1007/s00024-008-0415-8

Heidarzadeh, M., Pirooz, M.D., Zaker, N.H., & Yalciner, A.C. (2009). “Preliminary estimation of the tsunami hazards associated with the Makran subduction zone at the northwestern Indian Ocean.” *Natural Hazards,* 48(2), 229–243. https://doi.org/10.1007/s11069-008-9259-x

Heidarzadeh, M., Pirooz, M.D., Zaker, N.H., Yalciner, A.C., Mokhtari, M., & Esmaeily, A. (2008b). “Historical tsunami in the Makran Subduction Zone off the southern coasts of Iran and Pakistan and results of numerical modeling.” *Ocean Engineering*, 35(8–9), 774–786. https://doi.org/10.1016/j.oceaneng.2008.01.017

Jaiswal, RK., Singh, A.P., & Rastogi, B.K. (2007). “Past Tsunamis in the Arabian Sea and Future Possibilities.” *Indian Minerals,* 61 and 62, 75–82. https://www.researchgate.net/publication/236659042

Jaiswal, R.K., Singh, A.P., & Rastogi, B.K. (2009). “Simulation of the Arabian Sea Tsunami propagation generated due to 1945 Makran Earthquake and its effect on western parts of Gujarat (India).” *Natural Hazards*, 48(2), 245–258. https://doi.org/10.1007/s11069-008-9261-3

Lisitzin Eugenie. (1974). “Sea-Level Changes. Elsevier Scientific Publishing Company.”

Macmurdo C. (1821). “Account of the earthquake which occurred in India in June 1819.” Edinburgh Philos , 4, 106–109.

Mex, L. (2003). “Handbook for Estimating the Socio-economic and Environmental Effects of Disasters. Economic Commission for Latin America and the Caribbean.”

Murty, T.S., Bapat Pune, C.A., Solem, J.C., Paine, M.P., Baird Coastal Engineers, W.F., Fernandez, M., Havsokv, J., Atakan, K., Curtis, G.D., Pelinovsky, E. N., Pararas-Carayannis Honolulu, G., & Usa, H. (1999). “Tsunamis On the Coastlines Of India.” *The International Journal of The Tsunami Society*, 17. http://epubs.lanl.gov/tsunami/

Nelson C. (1846). “Notice of an earthquake and a probable subsidence of the land in the district of Kutch, near the mouth of Koree, or the eastern branch of the Indus in June 1845.” Geol Soc Lond.

Oldham, T. (1882). “A Catalogue of Indian Earthquakes from the Earlier Time to the End of A.D. 1869.” Memoirs of the Geological Survey of India, 19, 163–215.

Pararas-Carayannis, G. (2006). “The potential for tsunami generation along the Makran Subduction Zone in the Northern Arabian Sea. Case study: the earthquake and tsunami of November 28, 1945.” *Science of Tsunami Hazards,* 24.

Pararas-Carayannis, G. (2007). “Assessment Of India’s Vulnerability from Potentially Destructive Earthquakes And Tsunamis-Land Use and Engineering Guidelines in Alleviating Future Disaster Impacts and Losses.”

Patel, V.M., Dholakia, M.B., & Singh, A.P. (2016). Emergency preparedness in the case of Makran tsunami: a case study on tsunami risk visualization for the western parts of Gujarat, India. Geomatics, Natural Hazards, and Risk, 7(2), 826–842. https://doi.org/10.1080/19475705.2014.983188

Quittmeyer, R.C. (1979). “Seismicity Variations in the Makran Region of Pakistan and iran: Relation to Great Earthquakest.” (Roč. 117).

Rashidi, A., Dutykh, D., Shomali, Z.H., Farajkhah, N.K., & Nouri, M. (2020). “A review of tsunami hazards in the Makran subduction zone. In Geosciences (Switzerland).” (Roč. 10, Číslo 9, s. 1–31). MDPI AG. https://doi.org/10.3390/geosciences10090372

Rastgoftar, E., & Soltanpour, M. (2016). “Study and numerical modelling of 1945 Makran tsunami due to a probable submarine landslide.” *Natural Hazards*, 83(2), 929–945. https://doi.org/10.1007/s11069-016-2356-3

Rastogi, B. K., & Jaiswal, R. K. (2006). “A Catalog of Tsunamis In The Indian Ocean. In Science of Tsunami Hazards.” (Roč. 25, Číslo 3).

Rose Enid Teresa, A., Jerry Vasanth, G.D.N., & Vidya, C. (2020). “A review on the potential effects of tsunami on built environment.” Materials Today:

Proceedings, 33, 711–715. https://doi.org/10.1016/j.matpr.2020.06.019

Roshan, A.D., Basu, P.C., & Jangid, R.S. (2016). “Tsunami hazard assessment of Indian coast.” *Natural Hazards,* 82(2), 733–762. https://doi.org/10.1007/s11069-016-2216-1

Singh, A.P., Bhonde, U., Rastogi, B.K., & Jaiswal, R.K. (2008). “Possible Inundation Map of Coastal Areas of Gujarat with a Tsunamigenic Earthquake.” *Indian Minerals*, 61 & 62.

Smith, K. (2009). “Environmental Hazards: Assessing Risk and Reducing Disaster (5th ed.).” Routledge.

UNESCO-IOC. (2009). “Tsunami risk assessment and mitigation for the Indian Ocean: knowing your tsunami risk and what to do about it, IOC.” *Manuals and guides*; Vol.:52; 2009.

UNESCO-IOC. (2015). “Tsunami risk assessment and mitigation for the Indian Ocean: knowing your tsunami risk and what to do about it.”

Velioglu Sogut, D., & Yalciner, A.C. (2019). “Performance Comparison of Nami Dance and Flow-3d- Models in Tsunami Propagation, Inundation and Currents using NTHMP Benchmark Problems.” *Pure and Applied Geophysics*, 176(7), 3115–3153. https://doi.org/10.1007/s00024-018-1907-9

Yalciner, A., Reese, S., & Koshimura, F.I. (2011). “Tsunami coastal impact, damage information, and engineering aspects.” UNESCO-IOC.

Midstream

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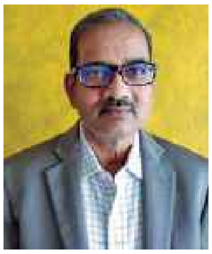


During the period of April to June 23, the IWWA Centres across India had multiple activities. The Council of Management meeting was held at Mumbai HQ office on 25/03/2023 and 29/04/2023. The world water day has been celebrated by IWWA Amaravati, Bengaluru, Coimbatore, Gwalior, Indore, Goa, Nagpur, Hyderabad, Jodhpur, Kolkata, Raipur, Ranchi and Pune Centres.

This is followed by World Environment Day celebration in the month of June 2023 by Vadodara, Ranchi, Prayagraj, Amaravati, Raipur, Goa, Nagpur, Aurangabad, Kolkata, Hyderabad, Gwalior, Mysuru & Mumbai Centres. Nagpur centre had monthly lectures including Late Dr P R Bhave Memorial lecturer by Dr S V Dahasahastra. Indore & Gwalior centres have observed the Public Health Engineer's Day. Blood donation camps, awareness programs about importance of water, Tree Plantations have been part of these celebrations. Students Chapter of the Indian Water Works Association (IWWA) has been installed at Government Polytechnic Bicholim Goa. The Water Resource Day has been celebrated by Meerut Centre. The next COM meeting has been planned at Kolkata Centre.

FORTH COMING EVENTS

NATIONAL & INTERNATIONAL EVENTS

Sr. No.	Events	Organizer	Date	Location
1.	Seminar on Rationales of Continuous Mode Water Supply (CMS) & Intermittent Mode Water Supply (IMS)	Indian Water Works Association Mumbai Centre	August 2023	IWWA HQ Mumbai
2.	The Water-A-Thon	Dr. B. Lal Institute of Biotechnology, IWA Grundfos Youth Action	5th August, 2023, Saturday 9.30 AM onwards	For Registration http://bit.ly/3qnzeYr
3.	18th EXPO Everything About Water	Earth Water Foundation	03-05 August 2023	Hall No.11, Pragati Maidan, New Delhi, India.
4.	Water to bring in India	MCI GeTS India Pvt Ltd	2025	India

HEAD QUARTER ACTIVITIES

COM Meeting at IWWA HQ Mumbai on 25/3/2023

Council of Members Meeting (COM) meeting at IWWA HQ Mumbai- 29th April 2023

NEWS FROM CENTRES :
AMRAVATI CENTRE

Celebration of World Water Day by Amravati Centre – Site Visits & Awareness Week on 16th March 2023

AURANAGABAD CENTRE

Celebration of World Environment Day by Aurangabad Centre

BANGALORE CENTRE

Celebration of World Water Day on 24/03/2023

COIMBTORE CENTRE

Celebration of World Water Day on 26/03/2023 and Environment Day --- Distribution of cloth bags in Vegetable market.

RANCHI CENTRE

Celebration of World Environment Day and World Water Day on 22/03/2023 – Discussion on Accelerating Change to Solve the Water & Sanitation Crisis.

GOA CENTRE

Installation of IWWA Student Chapter-IWWA Goa Centre, World Water Day, Earth Day Celebration and IWWA office Inauguration.

GWALIOR CENTRE

Celebration of Public Health Engineers Day on 07/04/2023 and World Environment Day on 5th June 2023.

HYDERABAD CENTRE

Celebration of World Water Day on 21st March 2023 – Speaker Dr.Sneha Latha, Water & Sanitation Consultant and Faculty, ASCI

INDORE CENTRE

Expert Talk on 16/02/2023, Workshop for Students on 16/02/2023, Public Health Engineers Day and World Water Day on 5th June 2023 along with Bhopal, Jabalpur and Gwalior Centre and Seminar on 24×7 Water supply by Dr Sanjay Dahasasra

JODHPUR CENTRE

Celebration of World Water Day by Jodhpur Centre

LUCKNOW CENTRE

Celebration of World Environment Day by Lucknow Centre

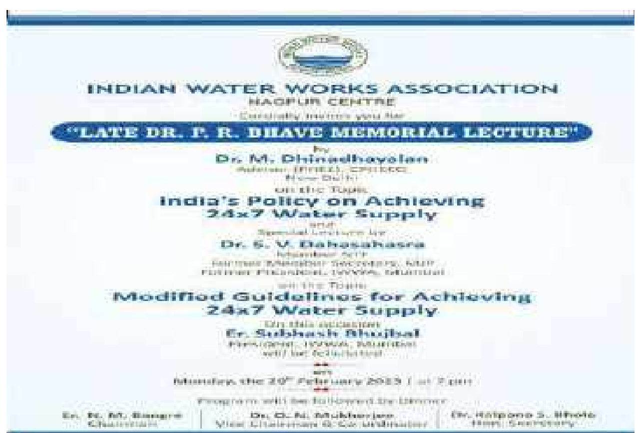
MEERUT CENTRE

Celebration of World Environment Day and Water Resource Day on 30/04/2023

MUMBAI CENTRE

World Water Dayay celebration by VJTI Students Chapter of IWWA on on 23/03/2023 --- Expert talk by Dilip Sonwane. World Env Day Celebration on June 23rd, 2023 --- --- Tree Plantation and Expert talk by Shri Ulhasas Paranjpe.

NAGPUR CENTRE


INDIAN WATER WORKS ASSOCIATION
NAGPUR CENTRE
"LATE DR. P. R. BHAVE MEMORIAL LECTURE"
Dr. M. Dhinadhayalan
India's Policy on Achieving 24x7 Water Supply
Dr. S. V. Dahasahasra
Modified Guidelines for Achieving 24x7 Water Supply
Er. Subhash Bhujbal

Late P R Bhave Memorial lecture on 20/02/2023 : Expert talk by Dr S V Dahasahsra and & Monthly Lecture Meetings

PUNE CENTRE

World Water Day at Nashik – Speaker Mrs Baste, Principal MVP Architecture College on Cleaning of Godawari River and it's Kundas, preservation of historical Baravs (Wells).

PATNA CENTRE

Meeting & Discussions on 08/02/2023 on Memberships and New Activities

PRAYAGRAJ CENTRE

Celebration of World Environment Day --- Tree Plantation

RAIPUR CENTRE

Celebration of World Water Day

VADODARA CENTRE

Celebration of World Environment on 05/06/2023

KOLKATA CENTRE

World Water Day 2023

Indian Water Works Association- Kolkata Centre

Indian Water Works Association Kolkata Centre celebrated **World Water Day** on 25th March 2023 with a focus on "**Solution to Plastic Pollution**".

Around 30 members from different profession have participated to celebrate **World Water Day 2023**.

Prof. **Arunabha Majumder, Chairman of Kolkata Centre as well as Professor Emeritus, School of Water Resources Engineering, Jadavpur University** inaugurate the ceremony by delivering a welcome speech and on the theme of the World Water Day.

Dr. Pragyan Bharati, WASH Specialist, UNICEF, Office for West Bengal delivered her presentation on: "**Accelerating change to address evolving water and sanitation crisis**". She describes the Global as well as National scenario of water and sanitation crisis and suggested few measures to get the solutions to the basic problems. All the participants took part in the discussion after her deliberation.

Finally, **Dr. Animesh Bhattacharya, Hon. Secretary, IWWA Kolkata Centre** deliver a concluding speech and vote of thanks.

Celebration of World Water Day on 25/03/2023

MYSURU CENTRE

Indian Water Works Association (IWWA),
Mysuru Centre

Karnataka Urban Water Supply & Drainage Board

World Environment Day

Dr. B. Manoj Kumar

Er. G.M. Madegowda

Guest of Honour

Sri Ranjan Bellarpady

Er. Shyam Prasad

All are Welcome

Members of Management Committee

Events

04:00 PM - 04:10 PM	Registration
04:10 PM - 04:15 PM	Inauguration
	Welcome Address
	Speech by Chief Guest
	Presidential Speech
Technical Lectures by Speakers:	
06:00 PM	Vote of Thanks
06:05 PM	High Tea

Webinar on World Environment Day on 5th June 2023

YAVATMAL CENTRE

IWWA Student Chapter at Jawaharlal Darda Institute of Tech Yavatamal is inaugurated in presence of Prof Arvind Mokadam, Director UFW.

USUAL FEATURES

IWWA's Membership strength as on 31st May, 2023

Life Fellow	1039
Life Member	10227
Life Organisation Member	590
Student Member	651
Total	**12557**

New Life Fellows

LF – 1360	Mr.A. Azhaguvel, Chennai.Tamil Nadu.
LF – 1361	Dr.Borkar Rewat Kumar, Nagpur, Maharashtra
LF – 1362	Mr.Sada Nand Mondal, Ranchi, Jharkhand
LF – 1363	Mr.Brij Nandan Kumar, Ranchi, Jharkhand.

New Life Organisation Members

LOM – 1050	M/s.Arya Engineering Services, Akola, Maharashtra
LOM – 1051	M/s.WATMOV Engineering Pvt. Ltd., Aundh, Maharashtra
LOM – 1052	M/s.Nileshkumar Infracon Private Limited, Ranchi, Jharkhand
LOM – 1053	M/s.Associates of Intellectual Mission, Coimbatore, Tamil Nadu
LOM – 1054	M/s.Shree Abhay Cranes Pvt. Ltd., Shegaon, Maharashtra.

Profiles of some of the Life Organisation Members:

LOM – 931

M/s. JAL PRAVAHIKA PVT. LTD.

23/24, Radha Bazar Street,
Kolkata – 700001, West Bengal
Tel : 033-22438675 Fax : 2210-1937
Website :www.jalpravahika.com
Email : akhil@jalravahika.com
Activities: Suppliers & Contractor & Manufacturers Representatives
Contact : Mr.Sonthalia Akhil, Director.

LOM – 932

M/s.TRUBA COLLEGE OF ENGINEERING & TECHNOLOGY, INDORE

Kailod Kartal, Bypass Road, RAU,
Indore – 452020, Madhya Pradesh
Tel : 0731-3240042, Mobile : 9893009147
Website : www.trubainstitute.ac.in,
Email : shardool.singh@hotmail.com
Activities : Teaching of Civil Engg. R& D, Guiding to Ph.D. Students,
Contact : Mr. Singh Shardool HOD (CE).

LOM – 933

M/s. SRF LIMITED

Sector 3, SEZ Indore, Pithampur,
Dist : Dhar – 454775, Madhya Pradesh.
Tel : 91 7292400201
Email : manoj.jain@srf.com,
Website : www.srf.com
Activities : Manufacturing of Polyester Chips & Films.
Contact : Mr.Jain Manoj, AVP Works.

LOM – 934

M/s. AAIMA ENGINEERING COMPANY

20, Shyona Estate, Dudeshwar Road,
Near Vadilal Ice Cream Factory, Tawadipura,
Ahmedabad – 380004. Gujarat.
Tel : 079-25632507 Mobile : 9898002507
Website : www. aaimaengineering.com
Email : aaimavalves@yahoo.in
Activities : Manufacturers of water plant,
Ro Part, Pipe Fitting industrial works for plant.
RO Water systems equipment.
Contact : Mr. Panchal Rakeshbhai Jayantilal, Proprietor (Director)

LOM – 935

M/s. J.D.J. ENTERPRISE

1/1A, Vansittart Row, 3rd Floor,
Room No.2A, Kolkata 70001
Tel : 033-22480952 Fax : 22488263
Email : s.saraogi@hotmail.com
Activities : Manufacturer of various plants and commissioned many bottling plants, arsenic removal plants, iron removal plants. etc.
Contact : Mr.Saket Saraogi, General Manager

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