REVIEW

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Fungal contamination and exposures in different water resources, hazards and remediation

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The fungi population in water has gained attention during the three decades. In this review, article attempt has been made to show its vulnerability as numbers of fungal species are now treated as water contaminants to indicate diseases in the human body. However, the importance of study of fungi has been less focused on surface water, groundwater systems and in agricultural wetlands. Time has come to correlate the population of fungi species isolated and identified from different sources of water-related with the climate change. The number of the fungal species are isolated and identified by the researchers may or may not have common occurrence but those definitely contaminate surface water at the different sources as well as different countries of the globe. In some cases, study has been made to analyze the occurrence of yeasts and filamentous fungi in the water body to investigate their correlation with bacterial indicator and faecal pollution[1].

Keywords: Ground water, climate change, filamentous fungi, faecal pollution, effects on human beings, remediation.

Introduction

Water is a primary requisite for life on earth but contaminants arising from incessant inflow and pollution of water bodies do have a myriad effect on ecology as well as on human body. It is necessary to protect consumers from water-borne diseases. The major problem is to get pathogen-free drinking water. Water utilities, however, rely solely on monitoring indicator bacteria, such as coliform and *Escherichia coli* (*E. coli*) to make sure microbiological quality of drinking water. In nature, there are abundance of coliform bacteria but these may not cause diseases. Their existence is often useful to indicate the potentially harmful bacteria may be present in the water whereas faecal coliform and *E. coli* originate exclusively from human and animal faecal wastes[2]. In this concern, the study has found out over 70,000 fungal species are existing in the environment in which unicellular yeast, filamentous fungi and multi cellular mould which is more or less 300 have been counted may spread the human diseases, and about dozen cause 90% fungal infections. Those involved various types of diseases, including allergies to fungal production of toxins, antigens and some directly invest host. Life-threatening disseminated infectious to other form of mucosal infections are being caused by several species of fungi.

Nowadays, there are reports in the media and the literature regarding occurrence of bacteria, yeast and filamentous fungi in treated and bottled mineral water too. Although causal relationships between fungal occurrence and water quality remains uncertain, a few cases of report being available where it is found fungal bioflims with in the municipal water distribution system. Filamentous fungi like *Penicilium* sp., *Aspergillus* sp. and *Candida* sp. have been investigated from potable water. Arvanitidou *et al.*, 1999 had investigated and isolated filamentous fungi from 82.5% sample and yeast from 11.1% from potable water of hospital and community samples[3]. It is witnessed an increase awareness about the potential for fungi to degrade complex natural substances due to broad enzymatic capabilities[4]. It was reported of their possible pathogenicity towards susceptible humans, animals. A few fungi produce mycotoxins that can display overlapping toxicities in vertebrates, plants and microorganisms[5].

A study shows, total and faecal coliforms, and total heterotrophic bacterial counts were estimated in parallel with counting of filamentous fungi and yeast in groundwater, in addition to some physicochemical parameters[6].

It is noticeable that total faecal coliform and heterotrophic bacteria estimated in a parallel method while studying or counting of filamentous fungi and yeast in bottled water and municipality's tap water[4].

It is interesting to note that developing countries are not taken into consideration of vulnerability of yeast and faecal coliforms, the measures and effects of mycotoxins in the human body, and more importantly resources of toxicological data, the analytical capacity to enforce regulations are less studied[7,8].

Discussion

In this review article, it has been observed that groundwater, surface water and other resources of water have contaminants of bacteria, filamentous fungi and other microorganisms which cause health hazard to human being and climate change may cause pollution of water higher in the last three decades.

Usually, microbial quality of water is measured by the microorganism using indicator mainly *Escherichia coli*[9]. However, bacterial indications are importantly determined for sanitary and public health safety, are more challenging while enterovirus and protozoa are more resistant against disinfection, evenmore, *E. coli* zero count doesn't signify the absence of other microorganisms[10,11]. Hence, heterotrophic plate counting method is a prime procedure for measuring the presence of fungi as it is used to indicate the concentration of changes of microorganism whether it is entering or growing in the treated drinking water or not[12,13].

Based on this above prospects, it is worth mentioning that many countries till are not taken into consideration the importance of fungi infection in treated drinking water. Further to that, the United State Environmental Protection Agency created the purpose of protecting human health and the environment by planning and implementing regulation law passed by the Congress[14]. Even more, EU Drinking Water Regulations (2004) implemented few terms and conditions for maintaining the standard of drinking water but the mentioned authorities did not concern about the treatment of fungi in water, while Sweden is the only country that currently measuring the fungi contaminations in treated drinking water. The Swedish Water regulation authorities set a permissible limit of treated drinking water that is 100 CFU of microfungi in 100 ml water is considerable and safe for human consumption[15].

Growth of fungi based on different sources and physico-chemical parameters

The colony of fungi, their growth, and bioremediation process are dependent on the pH value of water. It has been observed that the positive correlation between aquatic hyphomycetes and the value of pH which ranges in between 5 to 7 and confirmed cases found in groundwater studies while lower pH means acidic water have an influence for binding of heavy metals like manganese and cadmium to the fungal cell wall components, which is a boon for some fungi[16].

The amount of organic substance in water is related to the sources and the surface area of the water bodies. Small surface of water receives the most organic matter due to plant vegetation. Furthermore, surface water with a slow stream contains a rich amount of nitrate, nitrite, phosphate and other products of organic material degradation, such as debris, lignin, hemicelluloses, and cellulose[17,18]. Contrarily, human activates the water pollution along with fertilizers or industrial and house hold waste[19,20]. Even more, surface water contains high biomass and rich diversity of plant is degraded by filamentous fungi[21]. Hence survey has been conducted Globally and many European territories in order to get the presence of isolated fungi species in surface, ground, tap water, drinking water, municipal water bodies, and in water distribution systemetc belong to ascomycetous genera *Alternia, Aspergillious, Cladosporium, Fusarium* and *Gibberrella,* etc. (Table 1)[16,22].

Therefore, the correlation results between filamentous

Table 1. Source and isolated fungi

Country	Year	Sources	Isolated fungi	Ref.
Greece, Thessaloniki	1998	Tap water (hospital zone)	*Alternia* sp., *Aspergillius* sp., *Exophilia* sp., *Trichoderma* sp.	3
UK and USA	1996	Surface water	*Alternia* sp., *Aspergillius* sp., *Mucors* sp., *Phialophora* sp., *Pythium* sp.	49
Greece	2000	Municipal water	*Pennicillium* sp., *Aspergillius* sp., *Verticillium* sp., *Actinomycetales* sp., *Alternia* sp., *Cryptococus* sp., *Curvularia* sp., *Daratomyces* sp., *Helminthosporium* sp.	23
Poland	2000-2002	Water Distribution System	*Aspergillius* sp., *Cladosporium* sp., *Fusarium* sp., *Phialopphora* sp., *Sesquicikkium* sp.	50
Germany, North Rhine-Westphalia	1998/9 (12 months)	Drinking water	*Phialophora* sp., *Acremonium* sp., *Aspergillius* sp., *Cladosporium* sp., *Chalara* sp.	48
Portugal	2003-2004	Tap water	*Acremonium* sp., *Alternia* sp., *Aspergillius* sp.	51
Pakistan	30 samples taken	Municipal Water Body	*Aspergillus* sp., *Monodictys* sp.	22
Australia	2007-2008	Municipal water	*Cladosporium* sp., *Penicillium* sp., *Aspergillius* sp., *Alternaria* sp.	15
Saudi Arab	Once	Treated watersource in hospital and residential houses	*Alternia* sp., *Aspergillius* sp., *Acremonium* sp., *Cladosporium* sp., *Fusarium* sp.	52

fungi and total yeasts, and bacterial indicators of pollution (total coliforms, fecal coliforms and fecal streptococci) of studied groundwater samples. The obtained results represented that, filamentous fungi showed a strong proportional correlation (0.727 and 0.885)) with total coliforms, and fecal coli form saverage counts, accordingly, while filamentous fungi showed weak correlation (0.181) with faecal steptoccocci. Furthermore, total yeasts showed weak proportional correlation (0.065) with total coliforms average counts and weak reverse correlation (–0.154 and –0.128) with faecal coliforms and streptococci respectively, while Table 8 shows the correlation results between filamentous fungi and total yeasts

Table 2. Sampling sites of groundwater wells in Giza Governorate[6]

Sample Sites	Well names	Sample sites	Well name
1	Mazghouna	11	Meat AlKaed
2	Abu Rakhowan	12	Nekla
3	AL Badrashin	13	Alreka
4	Abuel Nomers	14	Gerza
5	Tami	15	Kafr Ammar
6	Ezbetsherif	16	Al Maktafia
7	Kafr Hamido	17	Kafr Hegazy
8	Berush	18	Al Rahwey
9	El Sheikh Zayed	19	Al Kata
10	Al Manaia	20	Galatma

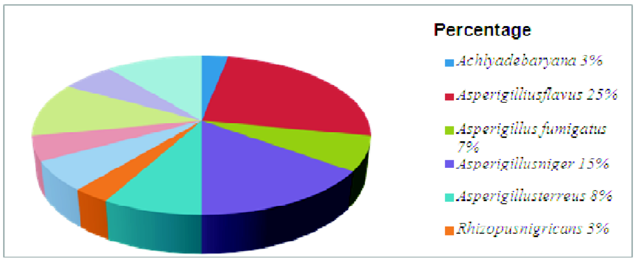

Fig. 1. Relative diversity of filamentous fungal species in groundwater samples[6].

counts. From the obtained statistical analysis, it can be observed that filamentous fungi showed reverse correlation with all measured physico-chemical factors except temperature and ammonia was proportional. In addition to this, total yeasts showed reverse correlation with some measured physico-chemical parameters (TDS, chloride, temperature, EC, nitrate, total hardness, and iron) and showed proportional correlation with BOD, COD, ammonia, sulphate, turbidity, and pH[6].

On the other hand, in the recent years in Giza, Egypt, individuals underlying more chronic diseases and immune suppression are exposed to potential pathogens like filamentous fungi and yeast cause the risk of gastroenteritis, pulmonary problems, skin ailments, etc. Now, mostly filamentous

Table 3. Used parameters and methods in groundwater wells in Giza Governorate[6]

Parameter	Unit	Measurement method
Electric conductivity (EC)	µS/CM	Conductivity method (APHA, 2005) using EC meter, Jenway, model: 470
pH		pH meter (WTW, Model pH, 315i)
Temperature	°C	Mercury thermometer, GH Zeal Ltd., London, England
Turbidity	NTU	Turbiditimeter [10 b] a potable Hannaturbidimeter (model: HI 93703)
Iron	mg/L	Phenanthroline method
Ammonia and nitrate	mg/L	A colorimeter (Jenway 6510,England) at 410 nm
Chlorides	mg/L	Silver nitrate titrimetric method
Sulphate	mg/L	Turbiditimetric method using UV/Vis spectrophotometer, Unicam model UV4-200 (UK): at wave length 420 mm
Total hardness ($CaCO_3$)	mg/L	EDTA titrimetric method (APHA, 2005)
TDS	mg/L	APHA, 2005, Evaporation test method
COD	mg/L	Titrimetric method (APHA, 2005) using spectrophotometer (Dr/20000) for use at 600 nm
BOD	mgO_2/L	Winkler's iodometric method (APHA, 2005)

fungi and yeast are also considered potentially pathogens and their quantification is practically identical for determining the total counts[23].

Twenty four species of fungi were isolated from the collection of 40 water samples from Vembanadu wetland agroeco system. The fungi *Aspergillius* sp. almost significant to mention, was five species, followed by *Curvularia*sp. and *Penicillium* sp. (3 species each). The prevalence of *Aspergillius niger* was noticed (50%) followed by *Penicillium* sp. (40%), while *Paecilomyces* sp. and *Aspergillius flabus* were accounted for 22.5% each accordingly. Hence, detail colonial count of fungi tested (n = 40) in four different consecutive quarter were given in Table 9 and Table 10[24].

Public health implication of mycotoxigenic fungi

The presence of fungi are not taken into consideration until the report of fungal contaminated water was noticed in Finland and Sweden during the 1980s and 1990s[25,26]. Water borne filamentous fungi are acted as a pathogenic and allergenic which have an adverse effect on human health, mostly attacked immune-compromised patients[27]. Pathogenic fungi are also causing hostile infections which led to high mortality rates[3,28–31]. Consequently, mycotoxins are fungal poisons as secondary metabolites by the mycelia struc-

Table 4. Physico-chemical parameters of groundwater samples at Giza, Egypt Governorate[6]

Parameter Sample No.	Ammonia (Mg/L)	Nitrate (Mg/L)	Sulphate (Mg/L)	Iron (Mg/L)	TDS (Mg/L)	Chlorides (Mg/L)	Total hardness (Mg/L)	BOD	COD	pH	Temp. (°C)	EC (s/cm)	Turbidity (NTU)
1	1.4	5.75	30.5	554	435.6	108	300	0	8	7.36	28	660	0
2	1.86	8.27	35.6	0.67	374.4	84	280	0	12	7.3	22	567	4.64
3	1.42	3.42	31.1	0.67	335.7	76	250	0	12	7.25	27	539	2
4	1.49	3.34	36.45	0.98	414.4	84	300	1	21.4	7.78	25	628	7.76
5	1.4	7.51	34.17	0.67	431.6	92	310	1	13	7.36	28	654	4
6	1	3.45	35.44	0.96	353.1	64	230	0	16.4	7.68	27	535	0.84
7	1.5	3.54	25.7	1.02	352.4	64	230	0	17.3	7.7	28	534	1
8	0.3	0.17	31.6	0.85	425	100	80	0	0	7.73	30	1022	0
9	0.8	2.84	34.86	0.66	449	125	482	0	0	7.62	32	628	5.9
10	0.69	9.82	26.1	0.56	448.8	92	314	1	16.3	7.76	28	680	4.55
11	0.89	2.47	32.9	0.56	413.8	56	292	1	19.3	7.73	29	627	8.1
12	1.5	9.77	30.06	0.57	369.6	80	240	0	12.4	7.36	23	560	0
13	1.74	1.59	38.6	0.9	413.8	84	272	1	19.8	7.79	28	627	8.81
14	1.35	3.32	34.33	0.71	341.8	56	204	0	14.9	7.79	22	518	8
15	1.36	3.45	35.12	0.25	534	121.7	321	0	22	7.7	28	516	19.9

Table-4 (contd.)

16	1	0.97	27.8	0.45	556	121.7	347.2	0	16.3	7.43	32	1027	0.25
17	1.86	1.5	34.87	0.54	412.9	79	320	0	11	7.34	27	760	4.35
18	1	1.07	33.14	0.22	505	138	105	0	0	7.26	34	449	6.2
19	1.86	5.78	37.78	0.68	560	109	340	0	11	7.56	28	780	6.98
20	0.98	5.37	38.35	0.56	389	125	270	0	0	7.68	28	690	5.76
Egyptian standards	0.5	45	250	0.3	1000	250	500	–	–	6.5–8.5	–	–	0–1

Table 5. Average counts of total bacterial counts, bacterial indicators, total fungi and yeast in groundwater samples[6]

Sample	TBC (cfu/ml)		TC	FC	FS	FF	Total yeasts
	At 37°C	At 37°C	(cfu/100 ml)	(cfu/100 ml)	(cfu/100 ml)	(cfu/100 ml)	(cfu/100 ml)
1	52	61	6	3	6	22	31
2	70	79	9	1	5	9	60
3	148	167	46	25	12	97	15
4	90	112	12	7	4	56	20
5	118	125	32	16	8	78	19
6	94	108	17	8	6	64	0
7	115	119	21	10	1	89	84
8	50	57	0	0	0	7	3
9	16	25	0	0	0	4	12
10	63	72	7	2	6	8	19
11	152	170	29	12	4	96	180
12	58	72	14	6	1	77	37
13	60	69	4	1	2	9	130
14	64	80	18	4	3	29	211
15	84	120	15	5	4	20	75
16	103	135	18	9	1	47	5
17	126	148	37	13	6	89	92
18	60	81	10	23	0	119	56
19	75	94	20	19	5	77	0
20	70	85	40	21	3	97	16
Egyptian standards	≤ 50	≤ 50	≤ 2	≤ 1	≤ 1		

ture of filamentous fungi along with fungal spores[32]. However, mycotoxin producing species are filamentous *ascomycetes, basidiomycetes* and *deuteromycetes* with *Pencillium, Aspergillus and Fusarium* are the most mycotoxin producing fungi[33]. Chemical structure of mycotoxins vary significantly, basically contain low mass organic compounds. In other words, mycotoxins are minute and stable molecules, even, problematic to eliminate it which enters into the food chain[34]. Even though, mycotoxins are also ingested through food or water infested with poisonous fungi[35] or ingested as mycotoxins secreted by fungi without eating the fungus itself. Then mycotoxins cause tissue destructions, thrombosis, infarction, and other manifestations of mycosis[36] (Table 11).

Water treatment procedures and inactivation of fungi

Different methods are accounted for inorder to inactive the fungi and their mycotoxins from water, especially from drinking water.

Coagulation and flocculation: Sedimentation and flotation process remove many microorganisms and fungi as they are trapped within the particles and settled down at the

Table 6. Total fungal count and relative density isolated from groundwater samples[6]

Fungal sp.	Total count cfu/100 ml	R.D.*(%)
Filamentous fungi		
Achlya debaryana	30	1.5
Asperigillus flavus	271	13.4
Asperigillus fumigatus	78	3.8
Asperigillus niger	166	8.2
Asperigillus terreus	89	4.4
Rhizopus nigricans	38	1.9
Fusarium oxysporum	68	3.4
Mucor sativas	54	2.7
Paecilomyces varioti	119	5.9
Penicillium notatum	65	3.2
Penicillium egyptiaccum	116	5.7
Total yeasts		
Candida albicans	230	11.4
Candida glabrata	200	9.8
Saccharomyces cerevisiae	500	24.7
Total fungal count	2024	100

*R.D.: Relative Diversity.

Table 7. Correlation between filamentous fungi and yeast, and bacterial indicators[6]

	n	Correlation		
		Total coliforms	Fecal coliforms	Fecal streptococci
Filamentous fungi	20	0.727	0.885	0.181
Total yeasts	20	0.075	–0.154	–128

sedimentation tank, from which it is disposed of with the sludge[37].

Filtration methods: One of the rapids and filterismostly used method, do not have more retention time to remove all microorganisms from water which are hidden in the particles[38]. Fungi grow attached to a substrate and colonise filters in water treatment plants giving them an opportunity to resist water treatment[39]. However, after filtration, the final and most trusted process for annihilating pathogenic micro-organism is disinfection[40].

Disinfection: The use of disinfection in water treatment as a public health measure has shown a major decline in people contracting water-related diseases from drinking wa-

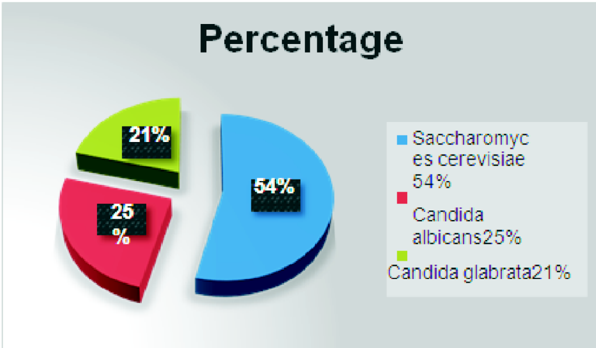

Fig. 2. Relative diversity of total yeasts species in groundwater samples[6].

Table 8. Correlation between filamentous fungi and yeasts, and physiochemical parameters[6]

	Correlation (n = 20)												
	TDS	chlor.	BOD	COD	Temp.	EC	Amm.	Nitrate	Sulph.	Total hardness	Iron	Turbidity	pH
Filamentous fungi	–0.081	–0.087	–0.082	–0.098	0.146	–0.231	0.161	–0.091	–0.002	–0.237	–0.153	–0.152	–0.366
Total yeasts	–0.295	–0.517	0.2	0.367	–0.303	–0.354	0.218	–0.222	0.106	–0.141	–0.017	–0.4	0.298

Table 9. Isolation of fungi from the surface water of Vembanadu wetland agro ecosystem[24]

Sl. No.	Fungi isolated	Frequency of occurrence (%)	Sl. No.	Fungi isolated	Frequency of occurrence (%)
1.	*A. corymbifera*	5	13.	*Fusarium* sp.	2.5
2.	*Aletrnaria* sp.	5	14.	*F. chlamydosporum*	2.5
3.	*A. candidus*	2.5	15.	*Mucor* sp.	5
4.	*A. flavus*	22.5	16.	*M. sterilia*	5
5.	*A. fumigatus*	10	17.	*M. sterilia (demateaceous)*	5
6.	*A. nidulans*	10	18.	*Paecilomyces* sp.	22.5
7.	*A. niger*	50	19.	*P. lilacinus*	2.5
8.	*Chrysosporium* sp.	17.5	20.	*Penicillium* sp.	40

Table-9 (contd.)

9.	*C. bertholletiae*	2.5	21.	*P. purpurogenum*	2.5
10.	*Curvularia* sp.	2.5	22.	*P. verrucosum*	2.5
11.	*C. geniculate*	5	23.	*S. brevicaulis*	2.5
12.	*C. lunata*	2.5	24.	*Trichoderma* sp.	2.5

ter[41]. Fungi and bacteria have a capability to live longer in verse situation in order to preserve their lives, while the factors are favourable again, they return to their normal state, recovering the metabolic activity and the generating spore germination[42]. However, the turbidity of the water is getting higher than 1 NTU usually with organic particles. Particles

Table 10. Quarterly isolated fungi of Vembanadu wetland agro ecosystem[24]

	Sample No.	CFU/ 100 ml		Sample No.	CFU/ 100 ml
First quarter	1	3	Fourth quarter	31	2
(January-March)	2	6	(October-	32	8
	3	8	December)	33	14
	4	12		34	0
	5	1		35	0
	6	4		36	6
	7	8		37	24
	8	11		38	16
	9	2		39	3
	10	1		40	9
Second quarter	11	30			
(April-June)	12	5			
	13	9			
	14	2			
	15	4			
	16	9			
	17	3			
	18	1			
	19	11			
	20	15			
Third quarter	21	6			
(July-September)	22	3			
	23	12			
	24	9			
	25	3			
	26	5			
	27	16			
	28	10			
	29	56			
	30	19			
	38	16			
	39	3			
	40	9			

Table 11. Fungal mycotoxins producing fungal genera and health effect[22]

Mycotoxin	Genera	Impact on Human Health
Aflatoxins	*Aspergillus* sp.	Human carcinogenic and others are hepatotoxic, aflatoxicosis, aspergillosis, nephropathy, teratogenic effect, susceptibility to HIV, TB etc.
Fumonisins	*Fusarium* sp.	Oesophageal cancer
Citrinin	*Aspergillus* sp., *Penicillium* sp.	Nephrotoxic, teratogenic etc.
Ochratoxin A	*Aspergillus* sp. and *Penicillium* sp.	Hepatotoxic, carcinogenic etc.
Patulin	*Aspergillus* sp., *Penicillium* sp., *Paecilomyces* sp.	Toxication on Immune system, cytotoxic, teratogenic, carcinogenic etc.
Sterigmatocystin	*Aspergillus* sp.	Carcinogenic
Cyclopiazonic acid	*Aspergillus* sp. and *Penicillium* sp.	Convulsions
Trichothecenes	*Fusarium* sp., *Trichoderma* sp.	Toxic aleukia
Deoxynivalenol	*Fusarium* sp.	Anorexia, vomiting, abdominal pain, diarrhoea, giddiness, convulsion etc.
T-2 Toxin	*Fusarium* sp.	Alimentary toxic aleukia
Zearalenone	*Fusarium* sp.	Carcinogenic
Ergot alkaloids	*Cladosporium* sp.	Ergotism in human body
Penicillic acid	*Penicillium* sp.	Carcinogenic
Tenuazonicacid, alternariol, alternuene, altertoxin-1	*Alternia* sp.	Inhalation allergy problems and mycotoxicoses
Ergotamine	*Claviceps purpurea*	Neurotoxins (Effect on nervous system)
Rhizonin	*Rhizopus* sp.	Hepatotoxic

interfere with disinfection as microorganisms are absorbed onto the surface of the particle[43].

Ozone: Ozone inactive fungi species by causing irreversible cellular damage[44]. But few isolated species have enough resistant agains to zone activation like *Trichodermaviride* and *Penicillium spinulosum*[39].

Free chlorine: Chlorine is a frequently used form of disinfection in water treatment plants in many countries. The chlorine is extensively used as a strong oxidant diminishing harmful microorganisms from water[45,46,47].

Conclusion

Hence, it is vast to explain that above-mentioned water samples are not always suitable for drinking purposes as because it is sometimes vulnerable to health. Consequently, it is clearly seen from the tables that different sources of water examined in order to recuperate with the solution. In addition to this, various mechanisms are taken into consideration but not always worthy of treated drinking water. Even though, isolated genera such as *Cladosporium, Phoma, Alternia, Aspergillus, Penicillium, Exophila, Fusarium, Acremonium, Exophaila* and *Phialophora,* etc. have an ability to resist against disinfection[48]. So, the documented pathogenic fungi from treated drinking water can no longer be ignored as water contaminants. While many countries are not still aware of the occurrence of fungi and their mycotoxins in treated drinking water supply network[22]. Monitoring and keeping the amount of fungi under surveillance after water treatment and in the distribution system is fundamental in guiding against harm to human health and also need to develop the aesthetic quality of water like taste and odour. Apart from this, the routine examination can be also challenging because cautious and experienced personnel are needed, though, this should not be underestimated further because fungi influence affecting diversely in waterbodies.

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