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Appendix A

Table A.1 Seasonal distribution of bioaerosol concentration (CFU/m³) at various outdoor sites

Agriculture field							
Seasons	Fungus (CFU/m ³)	Gram-negative bacteria (CFU/m ³)	Gram-positive bacteria (CFU/m ³)	WD (degree)	WS (m/s)	RH (%)	Temp (°C)
Monsoon	404±105	408±114	332±99	204±47	1.2±1.3	76±6	29±2
Post monsoon	742±106	726±116	924±146	184±34	0.6±0.4	63±12	22±4
Winter	717±71	257±71	720±137	195±33	1.0±0.4	66±10	19±5
Summer	777±109	956±149	758±159	210±20	1.7±0.9	56±14	33±3
Overall	664±177	520±295	682±243	198±36	1.1±0.8	66±12	25±7
Dumping site							
Seasons	Fungus (CFU/m ³)	Gram-negative bacteria (CFU/m ³)	Gram-positive bacteria (CFU/m ³)	WD (degree)	WS (m/s)	RH (%)	Temp (°C)
Monsoon	202±55	825±32	381±115	204±47	1.2±1.3	76±7	30±3
Post monsoon	1136±190	2565±310	630±134	184±34	0.7±0.4	72±6	23±5
Winter	540±149	1973±325	298±94	196±31	1.0±0.4	68±10	21±7
Summer	1695±243	1738±200	744±153	210±20	1.7±0.9	57±14	34±3
Overall	810±559	1789±639	470±218	199±35	1.1±0.9	68±12	26±7
Traffic site							
Seasons	Fungus (CFU/m ³)	Gram-negative bacteria (CFU/m ³)	Gram-positive bacteria (CFU/m ³)	WD (degree)	WS (m/s)	RH (%)	Temp (°C)
Monsoon	908±149	1126±200	1017±158	204±47	1.3±1.3	75±7	30±2
Post monsoon	1449±229	1203±209	1195±145	184±34	0.7±0.4	70±6	23±4
Winter	1100±197	1162±211	1219±230	197±30	1±0.3	66±11	21±6
Summer	870±186	2483±273	1365±271	210±20	1.7±0.9	57±13	33±3
Overall	1075±286	1422±580	1198±240	199±35	1.1±0.9	67±12	26±7

Table A2. Type of bioaerosols found at the various outdoor sites and their associated health effect

Bioaerosols	Sites	Agriculture	Dumping	Traffic	Nature of microbes	Effects of bioaerosols
Bacteria						
<i>Stenotrophomonas maltophilia</i>			Yes	Yes	Gram-negative	Nosocomial and pulmonary infection, pneumonia, urinary tract infection (UTI), and bloodstream infection in immunocompromised patients. Resistant to many antibiotics (Denton and Kerr, 1998; Korotetskiy et. al., 2022)
<i>Mammaliicoccus sciuri</i>			Yes		Gram-positive	Create toxic shock syndrome and multi-resistance (Nemeghaire et. al., 2014)
<i>Bacillus licheniformis</i>	Yes	Yes	Yes		Gram-positive	Nonpathogenic in nature but can cause causative ophthalmitis in immunocompromised bodies (La Jeon et. al., 2012; Maucour et. al., 1999), contaminates food (Salkinoja-Salonen et. al., 1999), especially dairy (Dhakai et. al., 2013)
<i>Acinetobacter sp.</i>	Yes	Yes	Yes	Yes	Gram-negative	Bacteremia, UTIs (Dent et. al., 2010), skin allergies (Hanski et. al., 2012)
<i>E. coli</i>			Yes		Gram-negative	No pathogenic but sometimes virulent strains can cause gastroenteritis, UTIs, neonatal meningitis, hemorrhagic colitis, and Crohn's disease (WHO, 2018)
<i>Brevundimonas vesicularis</i>	Yes	Yes	Yes	Yes	Gram-negative	Bilateral pneumonia and septic shock in an immunocompetent. Significant variability in antibiotic susceptibility (Stabler et. al., 2018)
<i>Enterobacter lactis</i>	Yes	Yes	Yes	Yes	Gram-negative	Nosocomial and less commonly community-acquired infections, including UTI, respiratory infections, soft tissue infections (Ramirez and Giron, 2022)
<i>Bacillus amyloliquefaciens</i>	Yes				Gram-positive	Not very harmful to human health, good for agriculture, protecting the plant from pathogens and act as biological control agents (Bai et. al., 2022)
<i>Acinetobacter baumannii</i>				Yes	Gram-negative	Pneumonia, Bloodstream infections, Meningitis, Wound and surgical site infections, including necrotising fasciitis, UTIs (Centers for Disease Control and Prevention, 2023)
<i>Acinetobacter calcoacetiuis</i>	Yes			Yes	Gram-negative	Cause pneumonia
<i>Bacillus sp.</i>			Yes	Yes	Gram-positive	Food poisoning (Ray and Ryan, 2004)
Fungi						
<i>Fusarium equiseti</i>	Yes	Yes	Yes	Yes		Adverse effects in agriculture (Tziros et. al., 2022), skin infection through mycotoxin (Gupta et. al., 2000)
<i>Cladosporium sphaerospermum</i>			Yes	Yes		Causes problems in patients with respiratory tract diseases, subcutaneous phaeohyphomycosis and intrabronchial lesions in immunocompetent individuals (Ng et. al., 2012)
<i>Aspergillus</i>	Yes	Yes	Yes	Yes		It can contaminate foods such as nuts, allergic disease, cause disease in many grain crops, especially maize, and cause neonatal infections (Cloherty, 2012)
<i>Talaromyces minioluteus</i>	Yes	Yes	Yes	Yes		Presumed to cause infection after the conidia are inhaled into the alveoli (Pitt, 2014)
<i>Periconia digitata</i>	Yes			Yes		Causes human corneal ulcers (Gunasekaran et. al., 2021)
<i>Cladosporium sp.</i>	Yes	Yes	Yes	Yes		Asthma and other respiratory diseases, skin infection, sinus, more commonly nasal congestion, sneezing, coughing, and itchy eyes (Ozdemir, 2015; Pomés et. al., 2016)
<i>Penicillium sclerotiorum</i>	Yes	Yes	Yes	Yes		Not very harmful effects are recognized

Appendix B

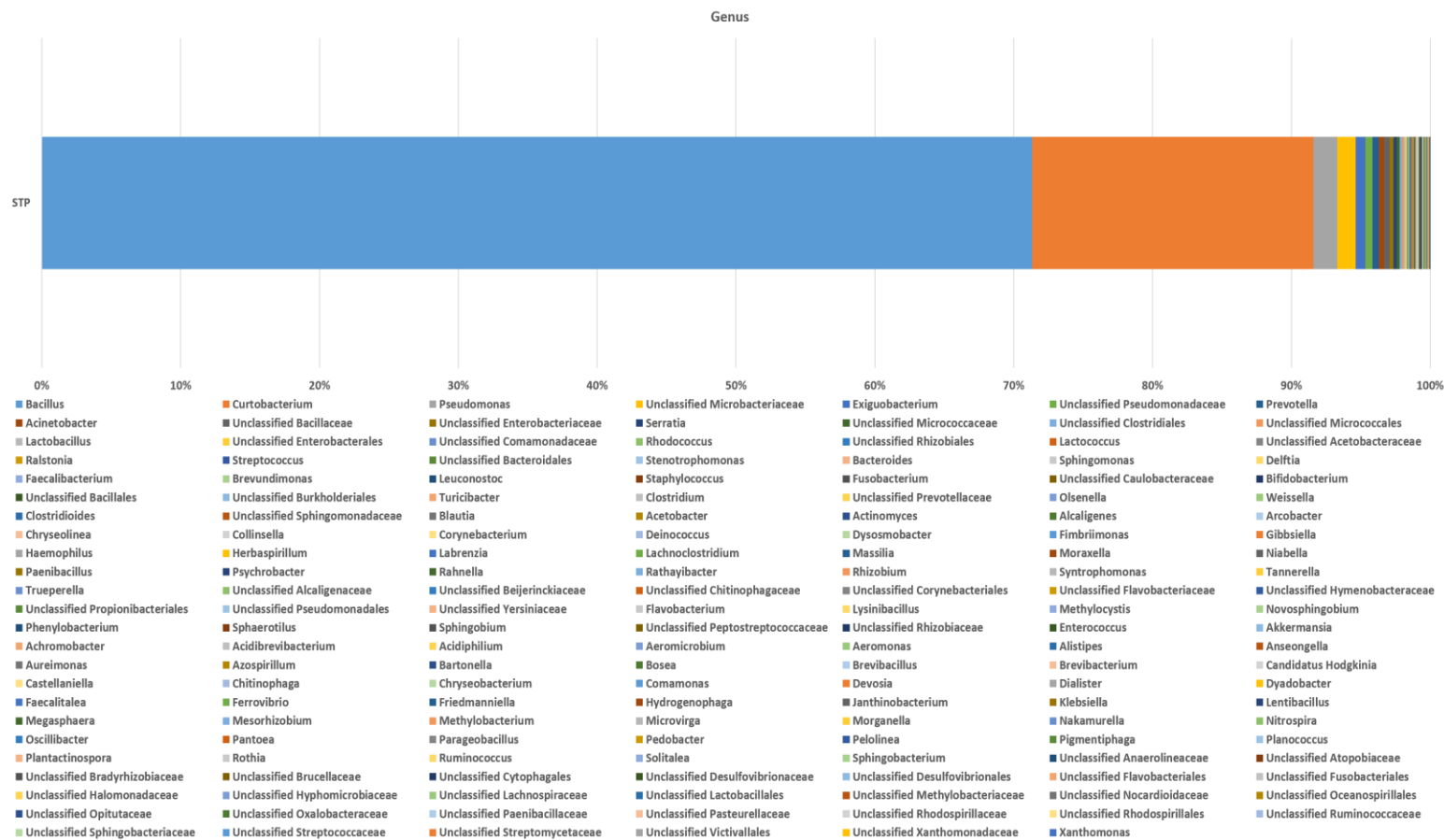


Figure B1 Metagenomics results at genus level of WWTP

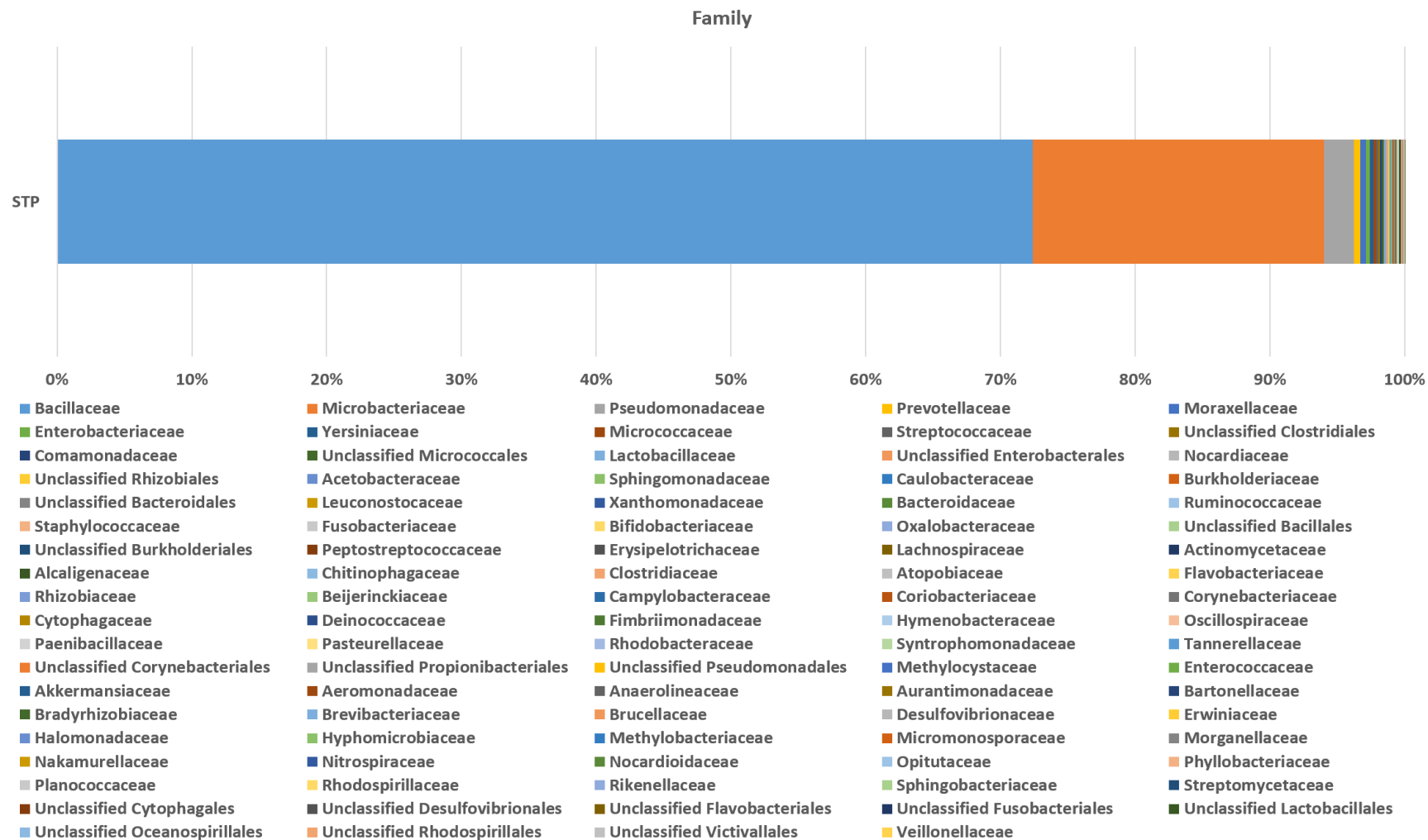


Figure B2 Metagenomics results at family level of WWTP

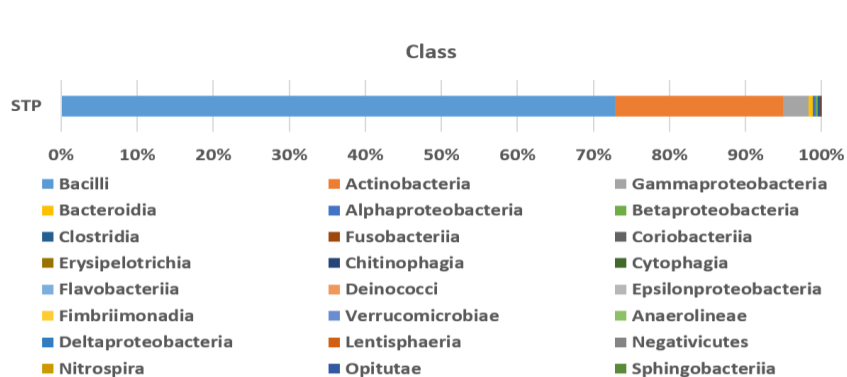


Figure B3 Metagenomics results at class level of WWTP

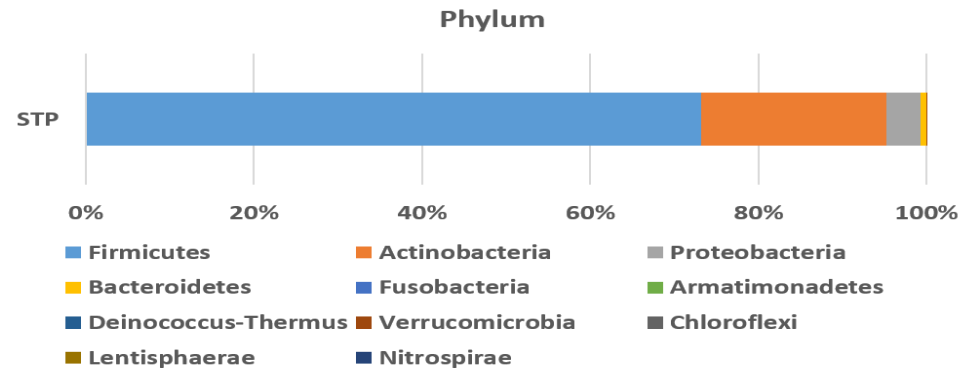


Figure B4 Metagenomics results at phylum level of WWTP

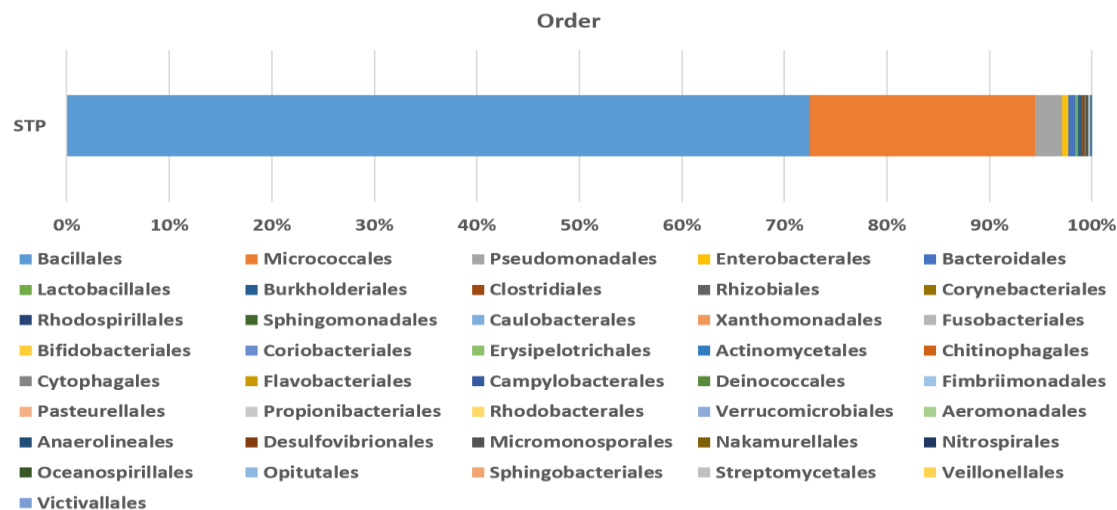


Figure B5 Metagenomics results at order level of WWTP

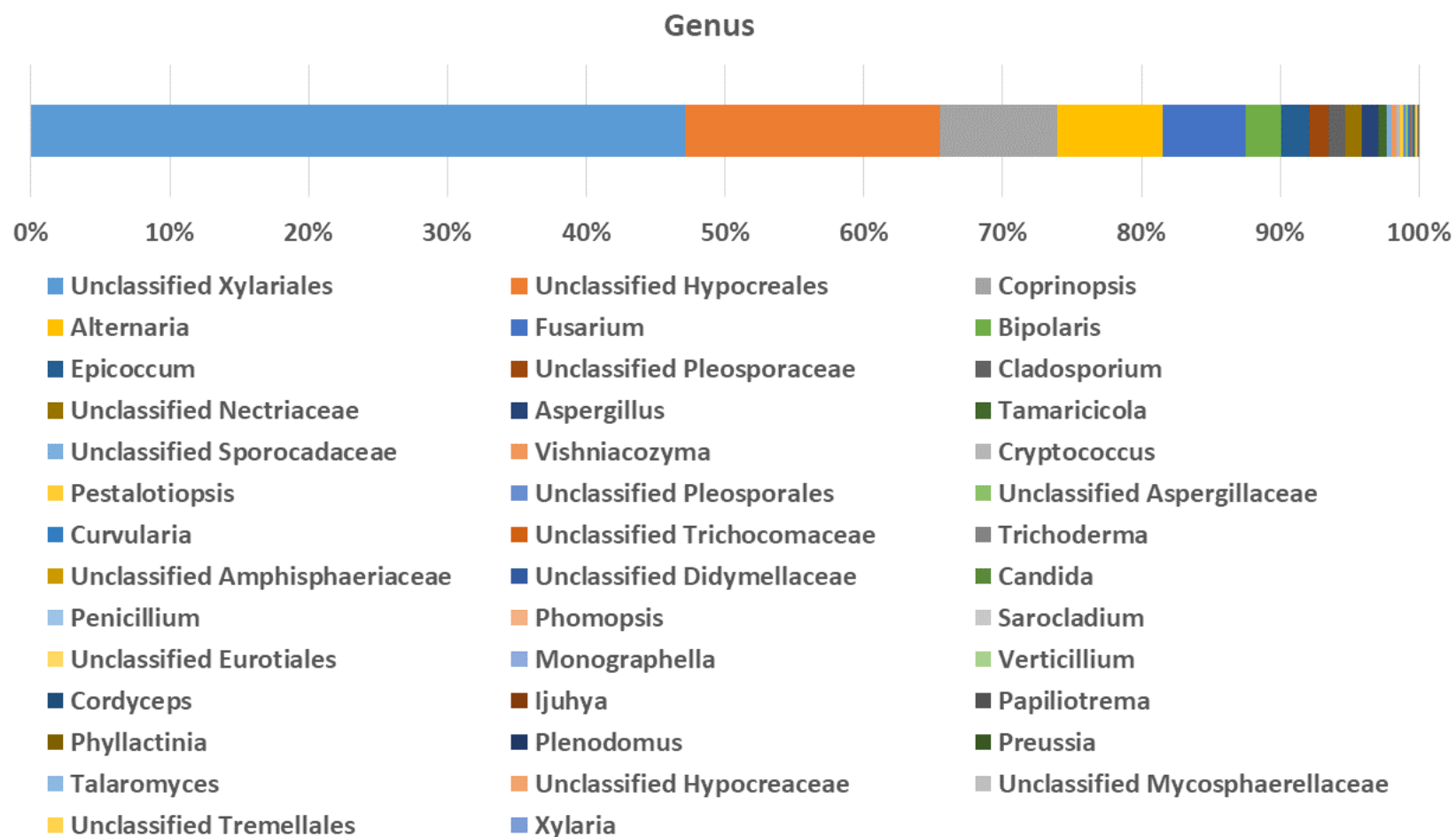


Figure B6 ITS metagenomics results at genus level of wastewater treatment plant

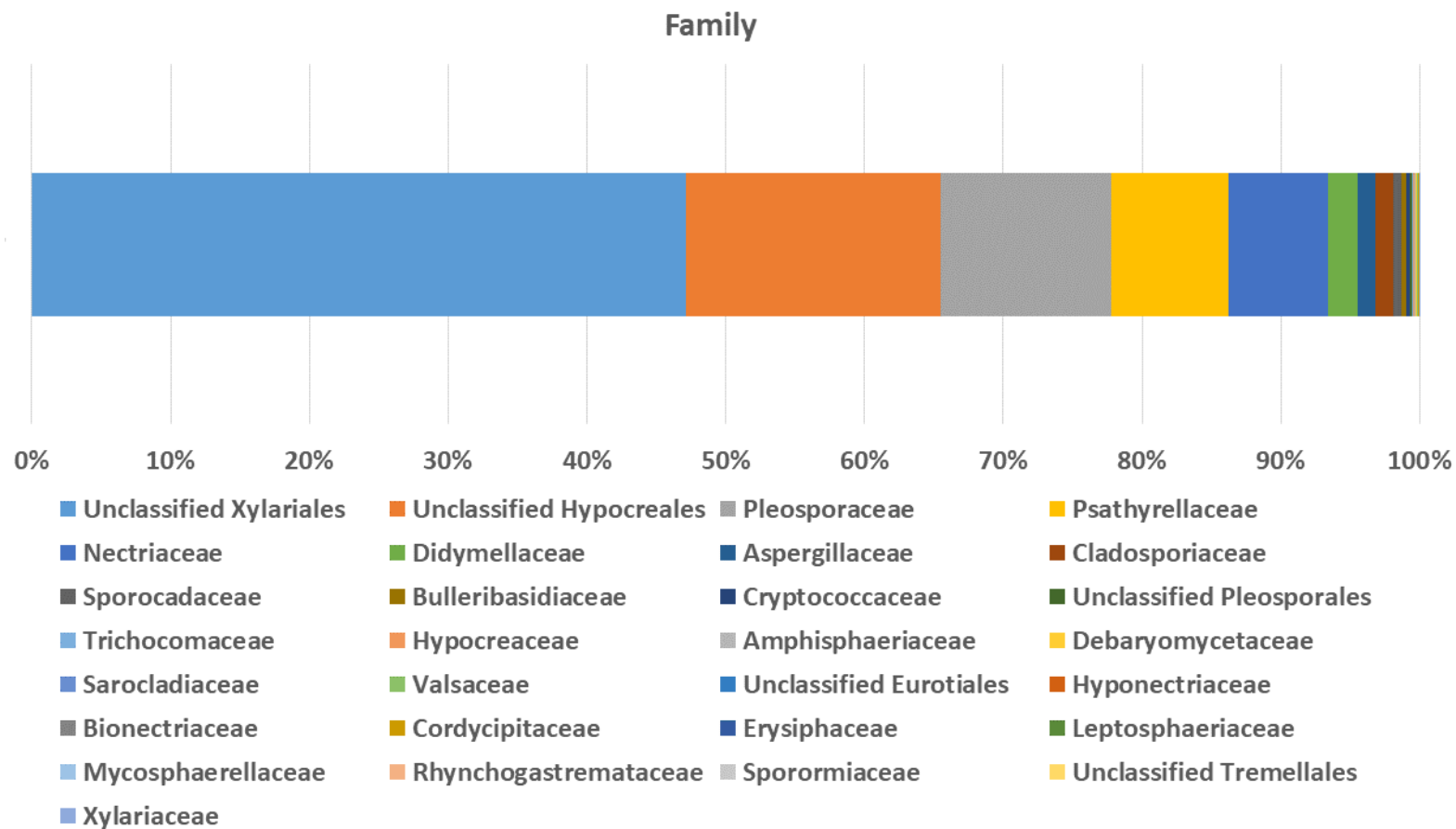


Figure B7 ITS metagenomics results at family level of wastewater treatment plant

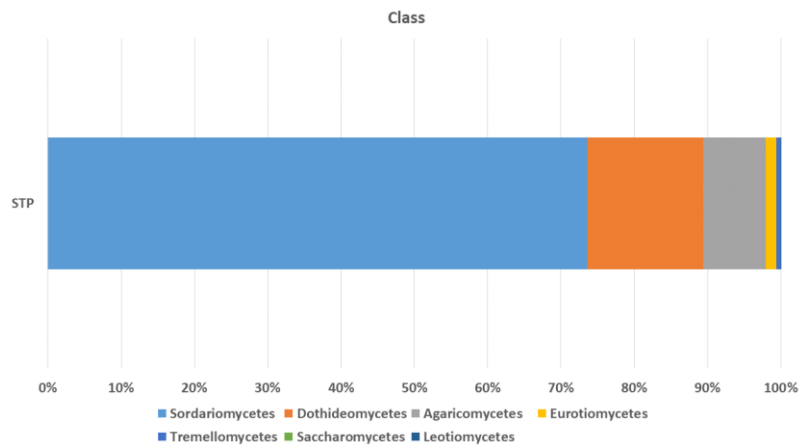


Figure B8 ITS metagenomics results at class level of WWTP

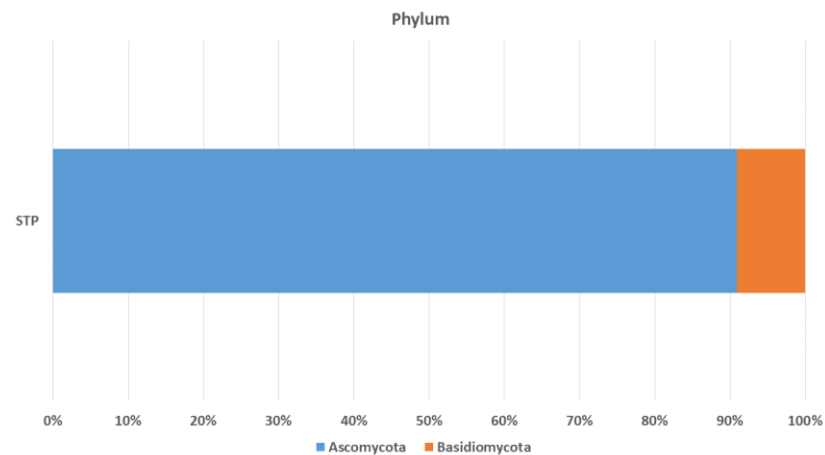


Figure B9 ITS metagenomics results at phylum level of WWTP



Figure B10 ITS metagenomics results at order level of WWTP

Questionnaires for the health effect of the bioaerosols on the human population near the Wastewater treatment plant

(fill in the blank spaces and tick the options)

Demographic information: Age....., gender.....,education....., occupation.....

Medical history: Previous health conditions....., current medications.....

Exposure history: Duration and frequency of exposure to the suspected source of pollution.....The proximity of residence to the source.....

Health symptoms: Respiratory symptoms (coughing, wheezing, shortness of breath),

Skin symptoms (rashes, itching), eye symptoms (irritation, redness), headaches, fatigue

Mental health: Stress, anxiety, depression

Environmental factors: Air and water quality, noise pollution

Lifestyle factors: Smoking history, alcohol and drug use

Occupational exposure: Job duties, use of personal protective equipment

Specific questions:

Have you ever lived near a wastewater treatment plant?

Have you noticed any respiratory issues such as coughing or shortness of breath in your daily life?

Have you experienced any skin irritation or rashes in the past year?

Have you experienced any eye irritation or redness?

Have you noticed any change in your sense of smell or taste in the past year?

Have you sought medical attention for any health issues you believe may be related to living near a wastewater treatment plant?

Do you have any concerns about the potential health effects of bioaerosols produced by the wastewater treatment plant?

Have you noticed any changes in the air quality or increased levels of foul odors in your community?

Are there any community-led efforts or initiatives to address any potential health concerns related to the wastewater treatment plant?

How satisfied are you with the information available to the public about the potential health impacts of bioaerosols near the wastewater treatment plant?

Other remarks (if any)

Appendix C

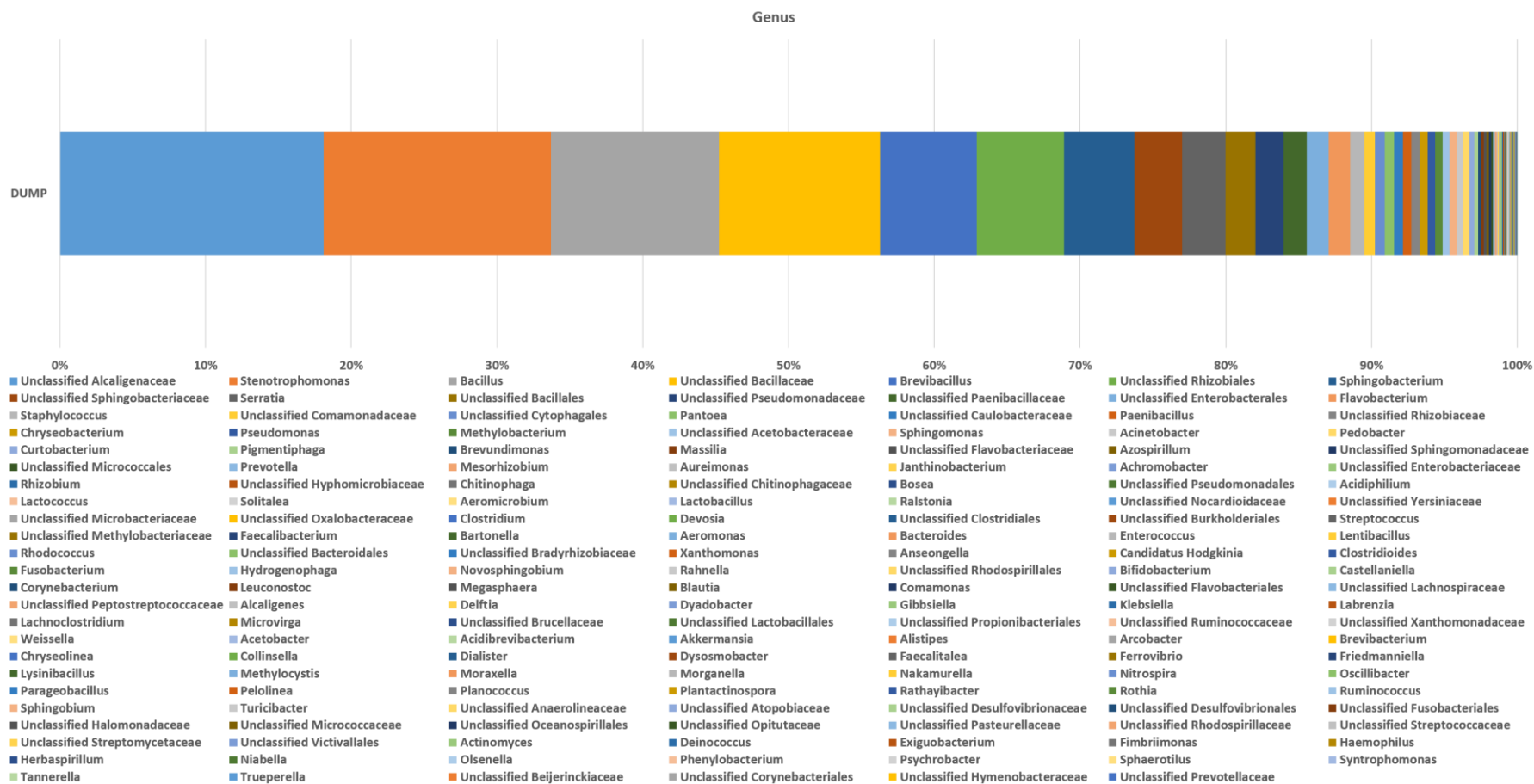


Figure C1 16s metagenomics results at genus level of solid waste treatment facility

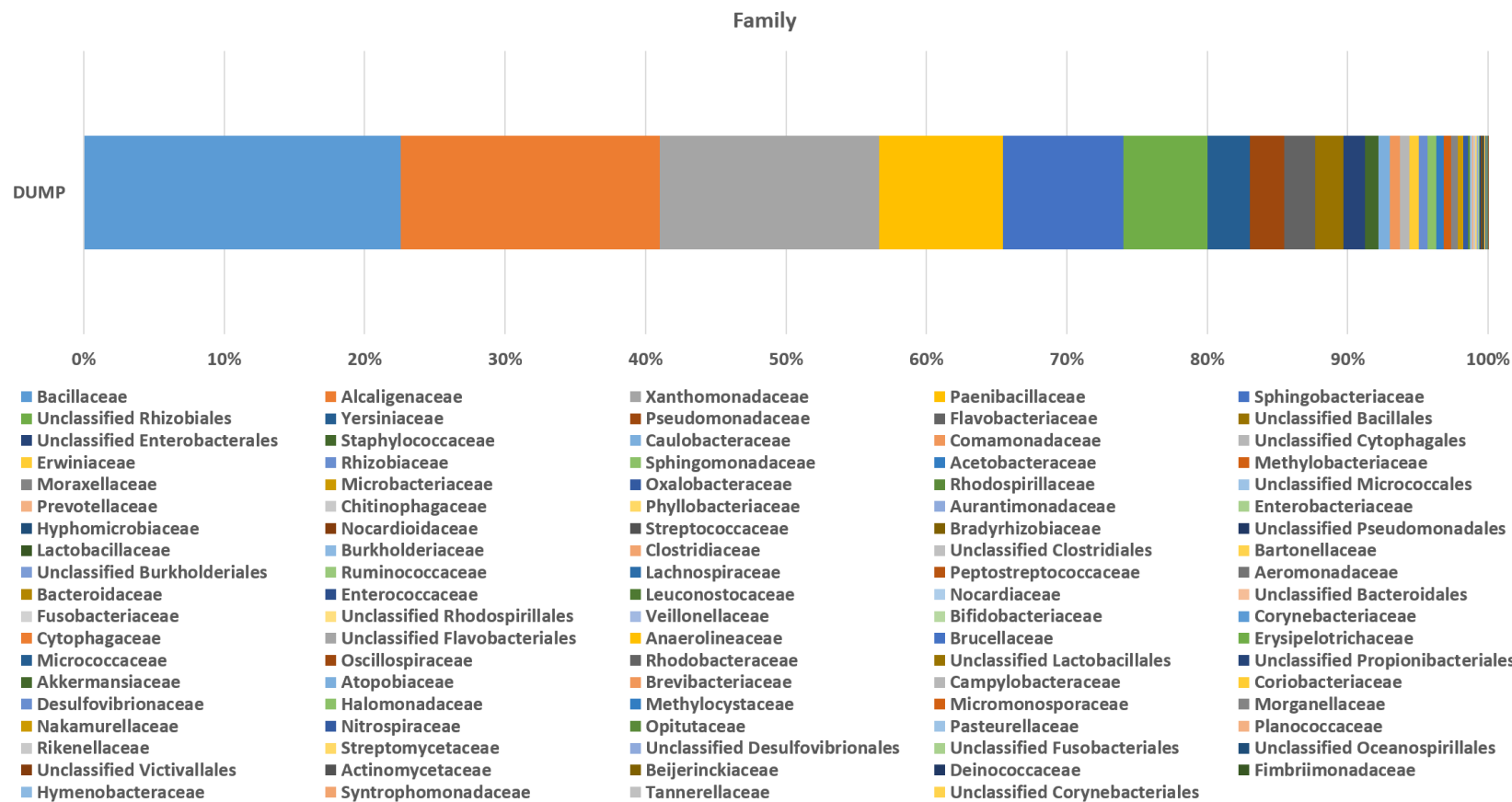


Figure C2 16s metagenomics results at family level of solid waste treatment facility

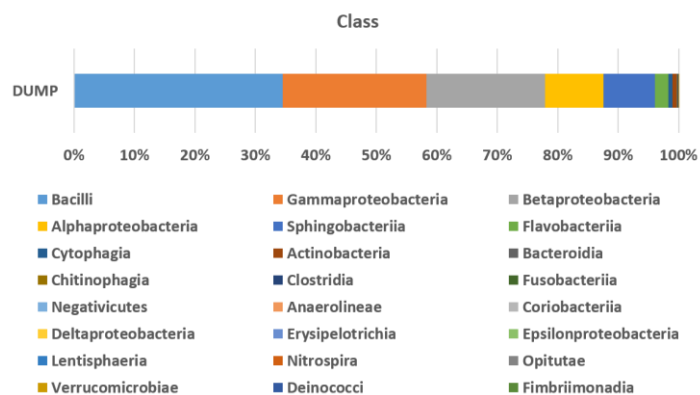


Figure C3 16s metagenomics results at class level of solid WTF

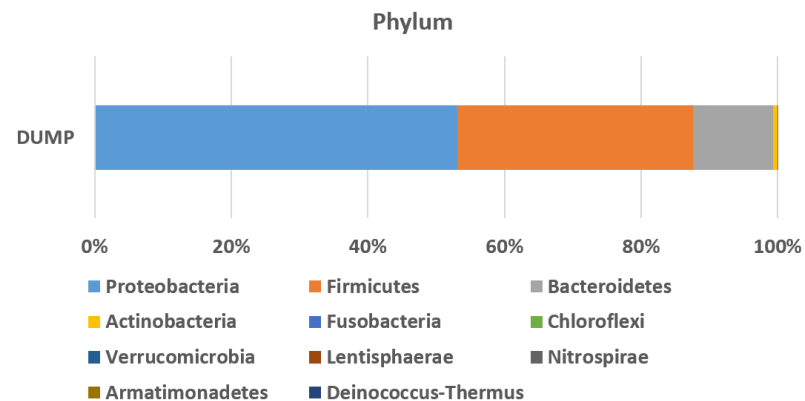


Figure C4 16s metagenomics results at phylum level of solid WTF

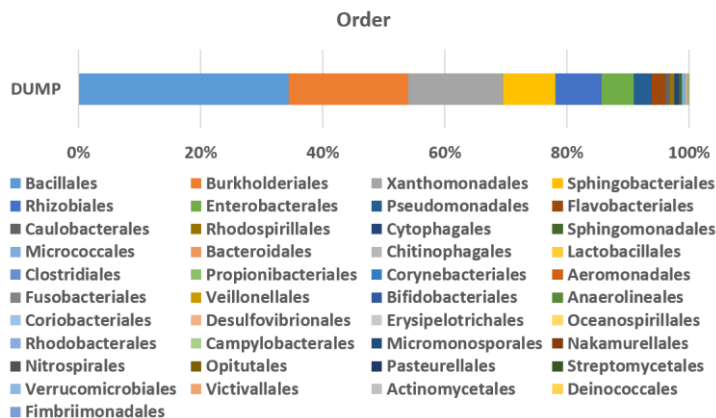


Figure C5 16s metagenomics results at order level of solid waste treatment facility

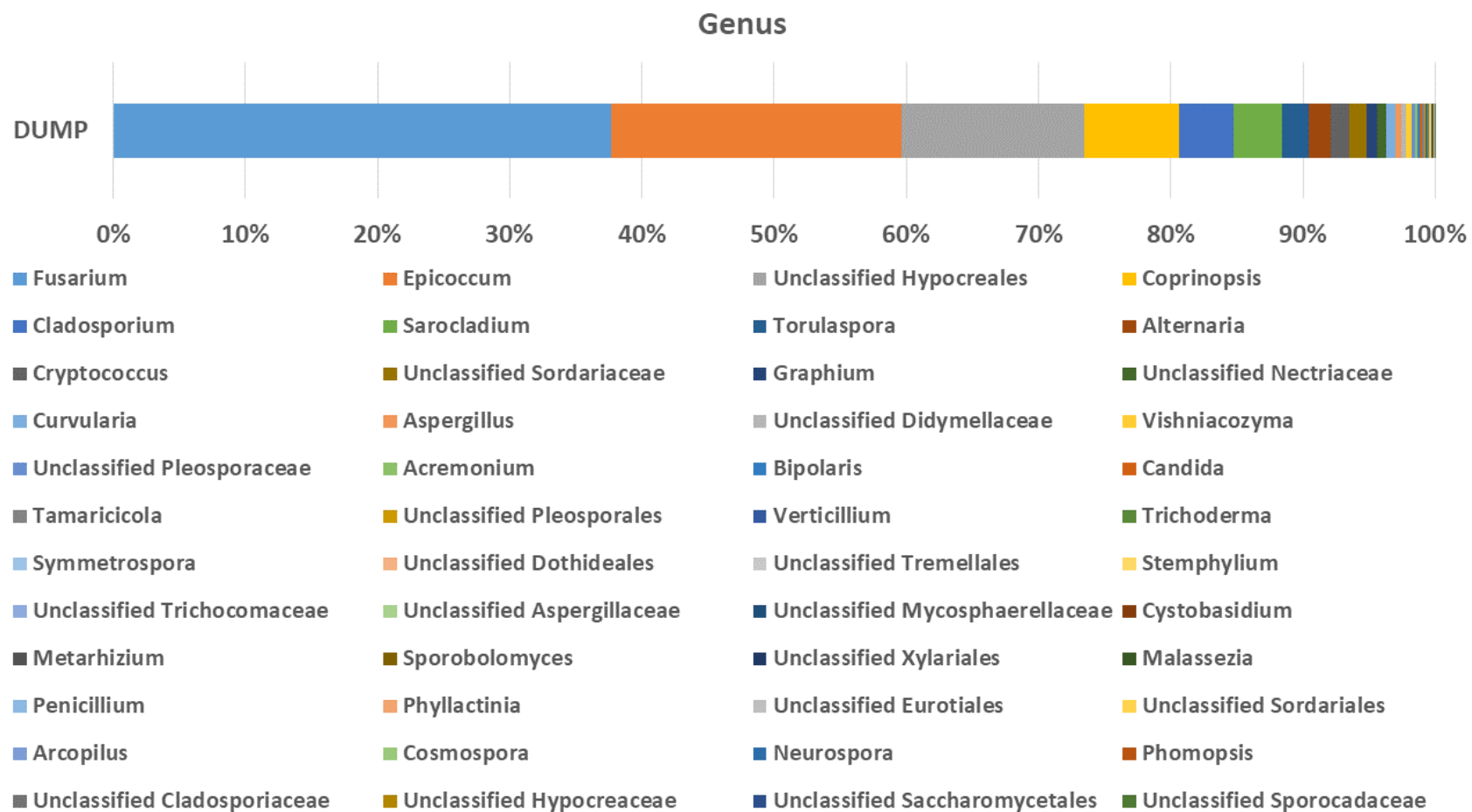


Figure C6 ITS metagenomics results at genus level of solid waste treatment facility

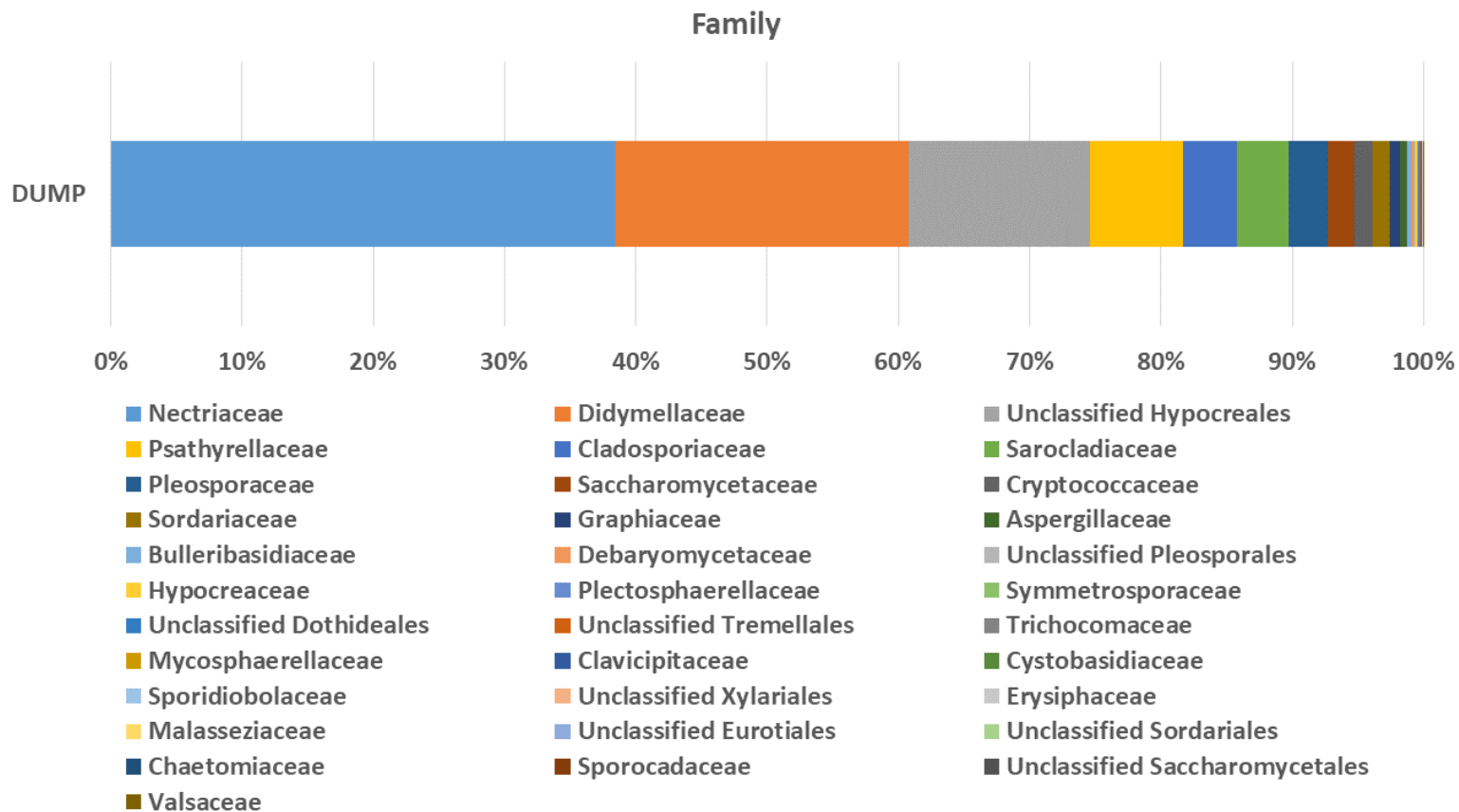


Figure C7 ITS metagenomics results at family level of solid waste treatment facility

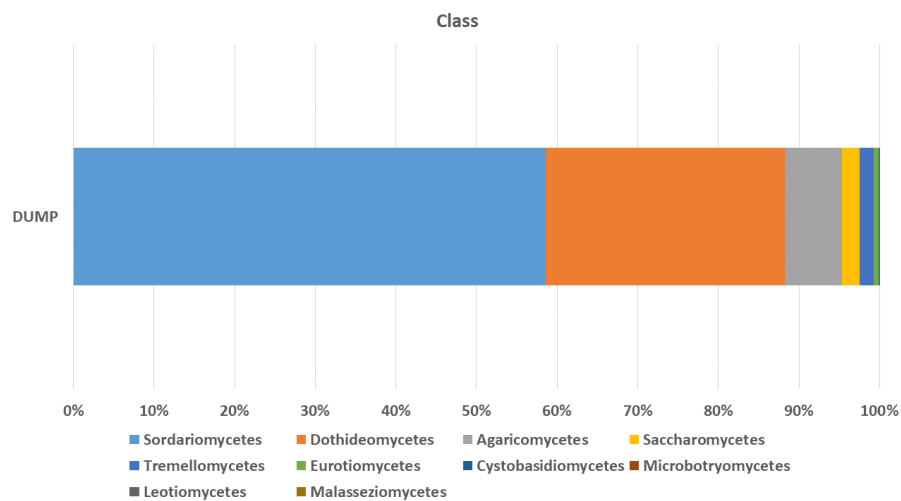


Figure C7 ITS metagenomics results at class level of solid WTF

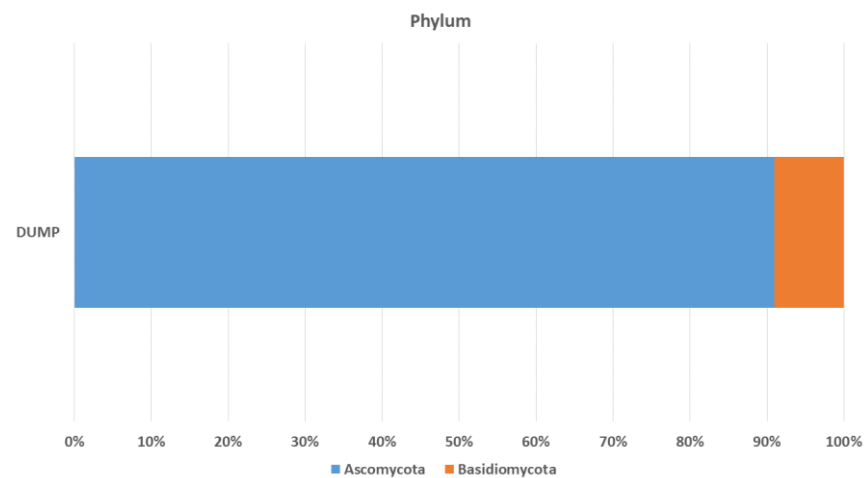


Figure C8 ITS metagenomics results at phylum level of solid WTF

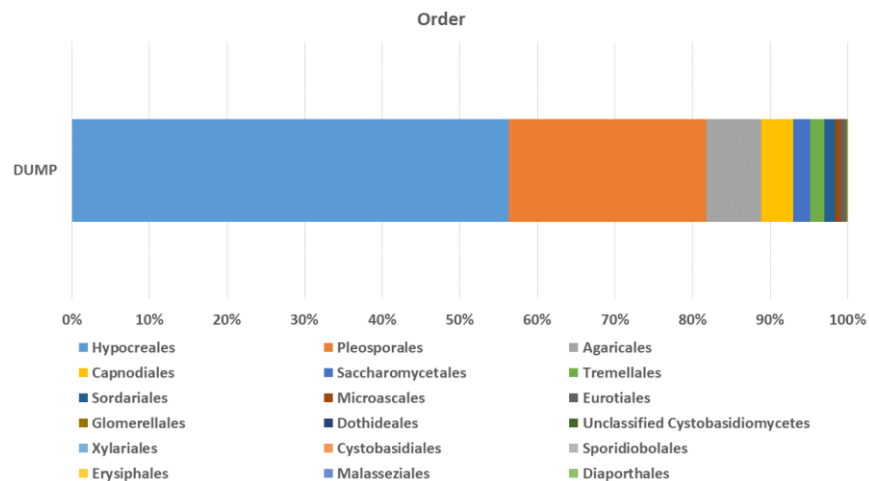


Figure C10 ITS metagenomics results at order level of solid WTF

Questionnaires for the health effect of the bioaerosols on the human population near the waste disposal site/dumping sites

(fill in the blank spaces and tick the options)

Demographic information: Age....., gender....., education....., occupation.....

Medical history: Previous health conditions....., current medications.....

Exposure history: Duration and frequency of exposure to the suspected source of pollution.....

The proximity of residence to the source.....

Health symptoms: Respiratory symptoms (coughing, wheezing, shortness of breath),

Skin symptoms (rashes, itching), eye symptoms (irritation, redness), headaches, fatigue

Mental health: Stress, anxiety, depression

Environmental factors: Air and water quality, noise pollution

Lifestyle factors: Smoking history, alcohol and drug use

Occupational exposure: Job duties, use of personal protective equipment

Specific questions:

Have you ever lived near a landfill?

Have you experienced any respiratory symptoms such as coughing, wheezing, or shortness of breath?

Have you experienced any skin irritation or rashes?

Have you experienced any eye irritation or redness?

Have you noticed any change in your sense of smell or taste?

Have you experienced any headaches or fatigue?

Have you sought medical attention for any health issues you believe may be related to living near a landfill?

Have you had any recent illnesses, such as colds or flu, that you attribute to living near the landfill?

Have you noticed any changes in your overall physical health since living near the landfill?

Do you feel that the landfill has impacted your quality of life in any way?

Are you aware of any health warnings or alerts related to the landfill? Are there any steps that you or the community have taken to mitigate the health effects of the landfill?

Other remarks (if any).....

Appendix D

Table D1 Descriptions of collected samples, sites, environmental variables and population

Site (Location details and specific characteristics)	Month of air sampling	Sampling frequency	No. of the population ^{*, \$} # while sampling	Total concentration bioaerosols (CFU/m ³)		Temperature (°C)	Relative humidity (%)
				Bacterial	Fungal		
Cowshed (Agriculture field surrounded by vegetation)	December 2019	Day 1	28 ^{\$}	492	448	17.8	87.8
		Day 2	28 ^{\$}	4028	337	19.8	90.1
	January 2020	Day 1	29 ^{\$}	3109	342	20.5	72.8
		Day 2	29 ^{\$}	1107	159	18.8	60.5
	February 2020	Day 1	27 ^{\$}	2984	286	23.9	61.6
		Day 2	27 ^{\$}	1346	344	21	82
	January 2021	Day 1	20 ^{\$}	2031	303	20.1	76.2
	February 2021	Day 1	35 ^{\$}	1949	406	19.3	85.6
		Day 2	26 ^{\$}	2553	249	21.6	65.8
	Poultry (Agriculture field surrounded by vegetation)	December 2019	Day 1	160 [*]	24869	704	20
Day 2			160 [*]	29187	330	21.4	77.5
January 2020		Day 1	170 [*]	22148	257	21.1	62.2
		Day 2	170 [*]	26123	220	18.8	60.5
February 2020		Day 1	180 [*]	21312	233	22.3	56.3
		Day 2	170 [*]	18519	275	21.4	72
January 2021		Day 1	150 [*]	19864	494	20.8	66.7
February 2021		Day 1	182 [*]	26753	219	19.6	61.8
		Day 2	198 [*]	24462	298	22.3	78.3
Canteen (Vicinity of IIT-BHU)		December 2019	Day 1	35-40 [#]	2644	212	17.2
	Day 2		30-35 [#]	1526	118	20.3	67.7
	January 2020	Day 1	40-45 [#]	3500	464	19.8	54.5
		Day 2	35-40 [#]	1280	113	20.2	61.7
	February 2020	Day 1	30-35 [#]	655	95	22.5	86.9
		Day 2	35-40 [#]	1883	204	21.5	83.2
	January 2021	Day 1	21-28 [#]	2480	282	19.1	78.3
	February 2021	Day 1	44-52 [#]	1476	218	20.6	58.2
		Day 2	30-35 [#]	1789	103	21.3	71.4
	Central library	December 2019	Day 1	50 [#]	279	174	17.6

(The central location of BHU)	January 2020	Day 2	57 [#]	743	197	19.7	63.3	
		Day 1	40 [#]	1471	143	20.2	59.7	
	February 2020	Day 2	52 [#]	595	88	20	57.8	
		Day 1	47 [#]	628	107	22.7	80.8	
	January 2021	Day 2	55 [#]	360	128	21.6	68.3	
		Day 1	53 [#]	1053	112	20.4	70.5	
	February 2021	Day 1	48 [#]	391	186	19.3	60.3	
		Day 2	58 [#]	594	121	21.2	63.4	
	Auditorium (Department of Chemical Engineering & Technology, IIT BHU)	December 2019	Day 1	116 [#]	312	97	17.9	77.1
			Day 2	154 [#]	367	275	17.2	72.2
January 2020		Day 1	90 [#]	1738	67	17.3	68.6	
		Day 2	130 [#]	411	468	19.2	74.2	
February 2020		Day 1	135 [#]	443	434	21.9	79.5	
		Day 2	110 [#]	362	286	20.1	74.1	
January 2021		Day 1	140 [#]	595	365	19.3	75.7	
		Day 1	102 [#]	633	297	18.1	73.9	
February 2021		Day 2	118 [#]	588	151	19.4	73.4	
		Day 1	90-95 [#]	1408	109	19.5	53.7	
SS Hospital (IMS, BHU, a teaching hospital)	December 2019	Day 2	90-95 [#]	4284	280	19.8	63.2	
		Day 1	90-96 [#]	2939	47	21.5	47.6	
	January 2020	Day 2	65-70 [#]	1263	127	21.8	56.2	
		Day 1	65-75 [#]	2268	146	24.4	77.8	
	February 2020	Day 2	81-90 [#]	1674	402	24.5	77.1	
		Day 1	55-65 [#]	3157	256	22.2	73.2	
	January 2021	Day 1	100-110 [#]	1592	133	22.4	60.1	
		Day 2	110-130 [#]	2169	167	21.1	59	
	Laboratory (Department of Chemical Engineering, IIT-BHU)	December 2019	Day 1	5 [#]	1215	68	19.4	74.1
			Day 2	4 [#]	234	95	19.3	60.3
January 2020		Day 1	6 [#]	381	86	19.2	58	
		Day 2	9 [#]	150	95	20.7	53.7	
February 2020		Day 1	5 [#]	90	134	21.6	62	
		Day 2	4 [#]	72	240	22.4	68	
January 2021		Day 1	2 [#]	948	207	21.2	70.1	
		Day 1	7 [#]	56	75	20.1	61	
February 2021		Day 1	7 [#]	56	75	20.1	61	
		Day 2	6 [#]	68	77	19.9	57	

*population of chicks, ^{\$}population of cow, [#]human population

Table D2 Concentration (CFU/m³) and size ranges of bacterial and fungal diversity in each site for the particular size range

Sites	Size											
	>7.0 µm (Stage1)		4.7-7.0 µm (Stage2)		3.3-4.7 µm (Stage 3)		2.1-3.3 µm (Stage 4)		1.1-2.1 µm (Stage 5)		0.65-1.1 µm (Stage 6)	
	bacteria	fungi	bacteria	fungi	bacteria	fungi	bacteria	fungi	bacteria	fungi	bacteria	fungi
Cowshed	583±242	42±18	411±326	29±15	234±248	35±13	475±475	69±32	239±233	104±50	233±104	38±32
Poultry	5098±1553	114±95	5171±3377	51±29	6352±3383	45±22	4111±1844	35±19	1995±1050	23±8	963±628	66±89
Canteen	677±774	25±22	251±103	27±16	265±119	32±21	272±127	40±26	268±176	57±43	179±122	18±17
Library	99±71	15±15	70±63	31±40	100±94	12±5	140±86	21±6	170±96	44±13	97±85	15±11
Auditorium	82±90	20±11	85±85	28±19	88±59	38±27	98±98	72±63	119±70	83±45	130±159	27±28
Hospital	657±312	33±21	373±208	29±27	286±110	21±16	392±263	32±34	414±321	41±32	181±13726	26±26
Laboratory	60±70	17±10	46±47	17±13	51±70	15±13	65±90	23±4	75±101	32±17	57±61	13±17

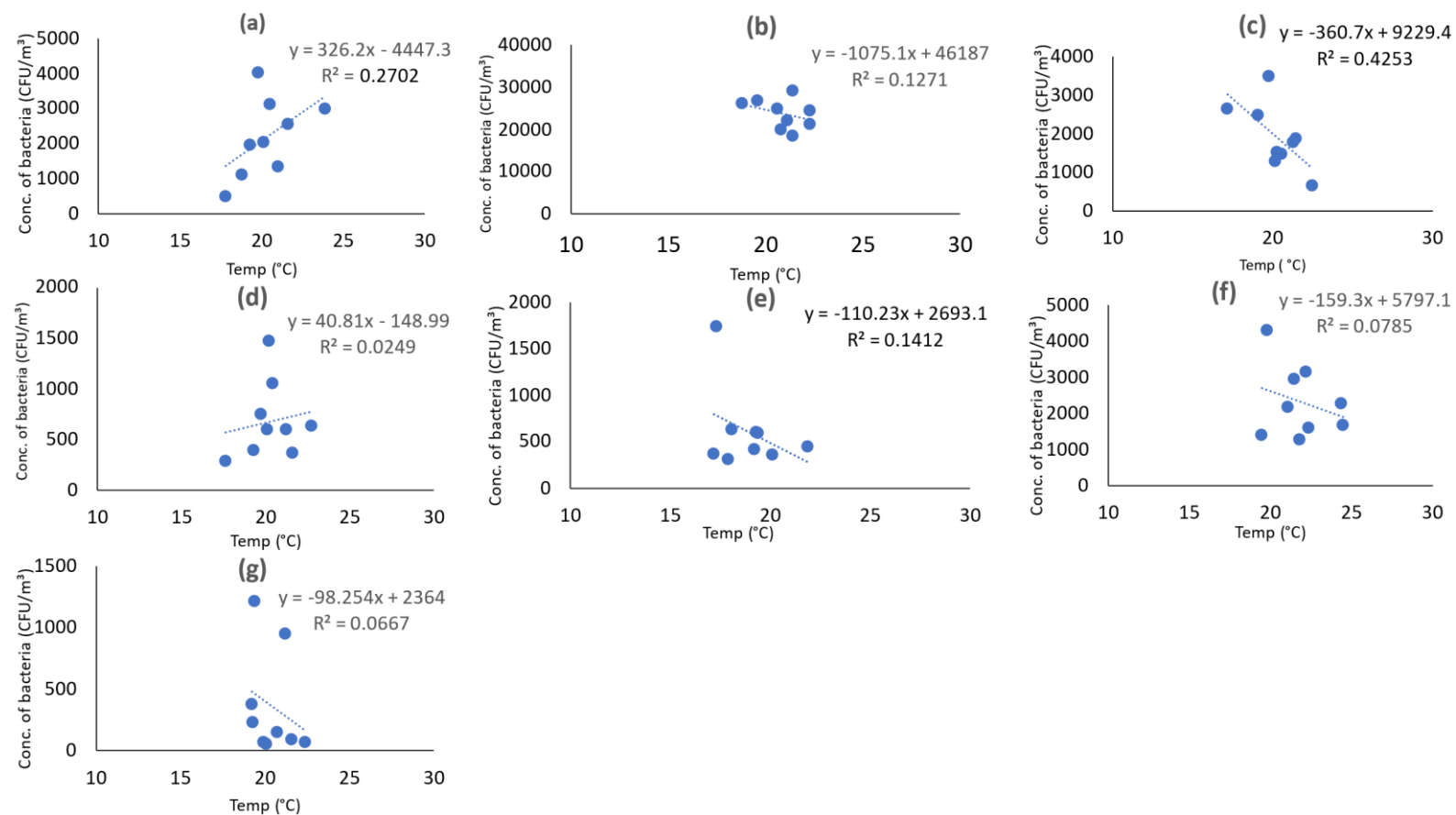


Figure D1 Variation of total concentration of bacterial bioaerosols with temperature at different indoor sites (a) cowshed, (b) poultry, (c) canteen, (d) library, (e) auditorium, (f) hospital and (g) laboratory

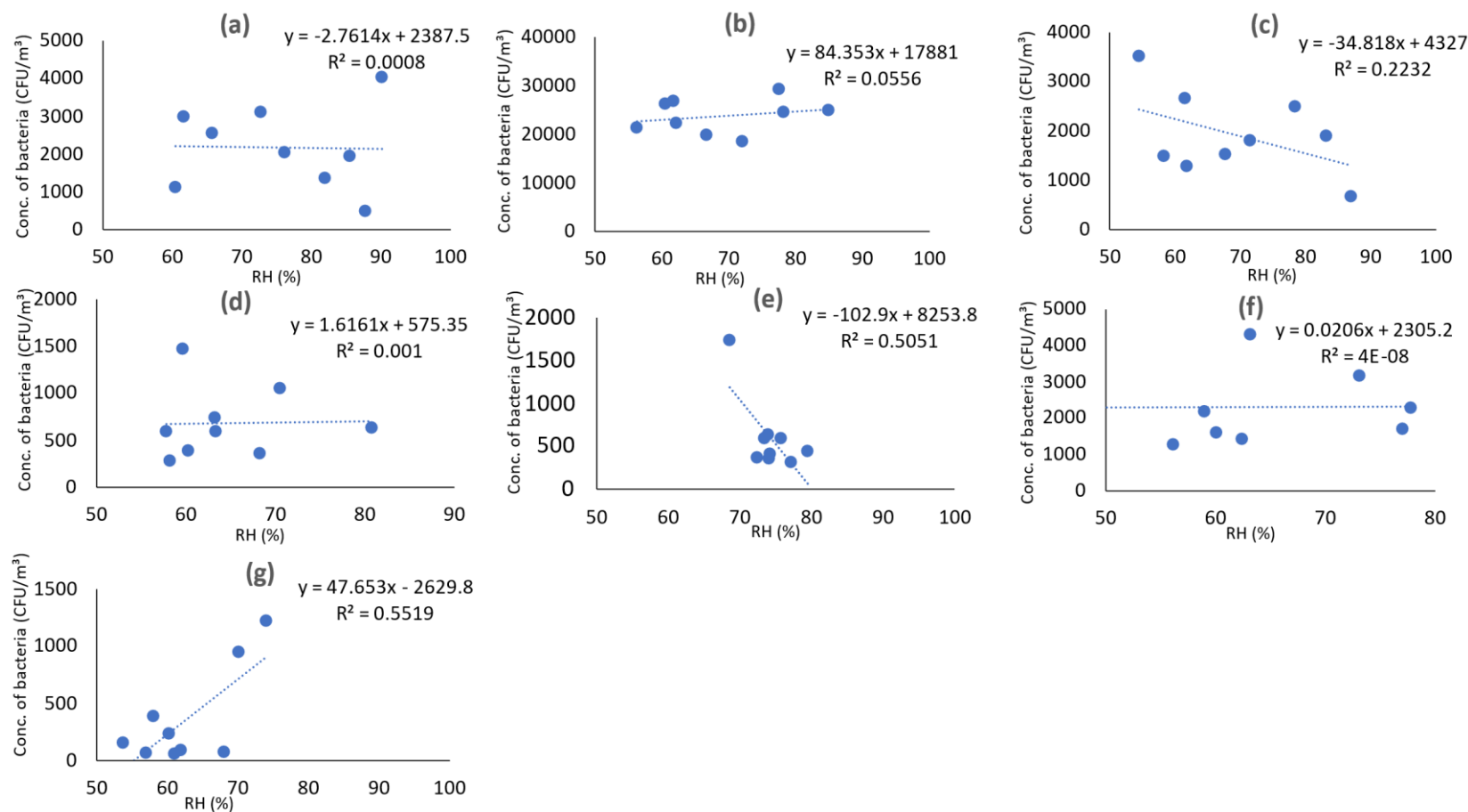


Figure D2 Variation of total concentration of bacterial bioaerosols with RH at different indoor sites (a) cowshed, (b) poultry, (c) canteen, (d) library, (e) auditorium, (f) hospital and (g) laboratory

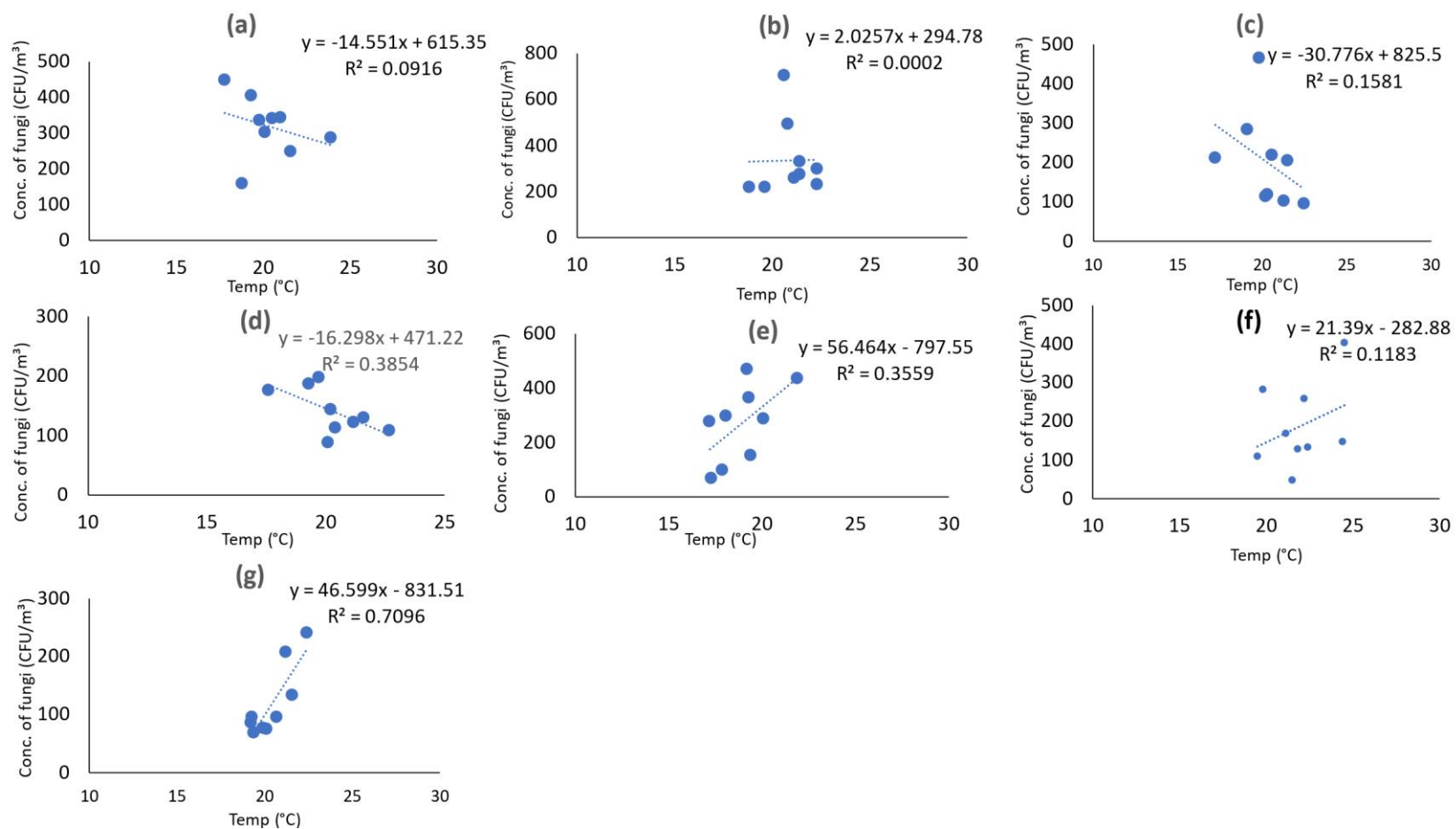


Figure D3 Variation of total concentration of fungal bioaerosols with temperature at different indoor sites (a) cowshed, (b) poultry, (c) canteen, (d) library, (e) auditorium, (f) hospital and (g) laboratory

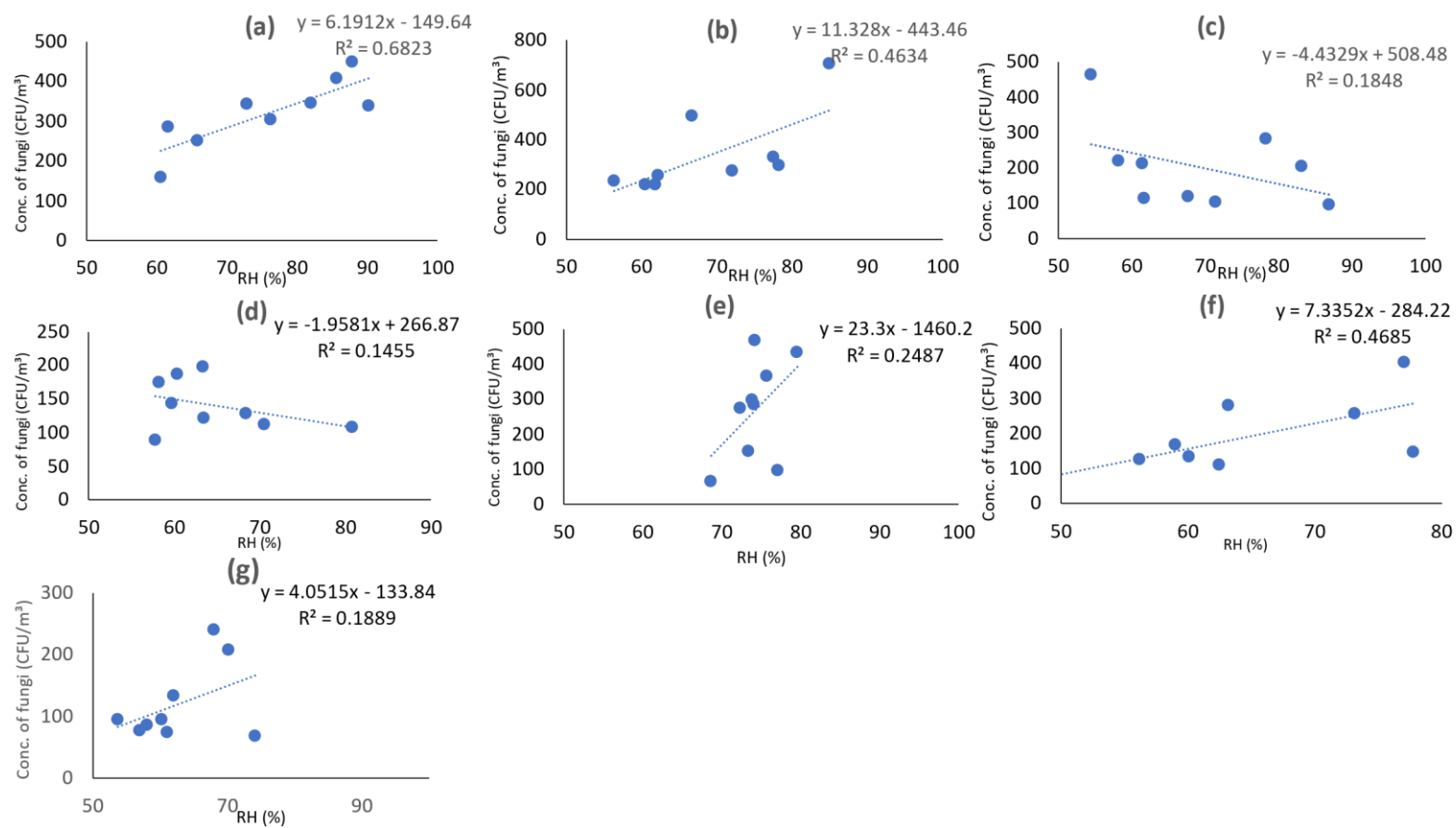


Figure D4 Variation of total concentration of fungal bioaerosols with RH at different indoor sites. (a) cowshed, (b) poultry, (c) canteen, (d) library, (e) auditorium, (f) hospital and (g) laboratory

List of publications

1. Vishwakarma YK, Ram K, Gogoi MM, Banerjee T, Singh RS. Bioaerosol emissions from wastewater treatment process at urban environment and potential health impacts. *Journal of Environmental Management*. 2024 Jun 1;361:121202.
2. Vishwakarma YK, Ram K, Gogoi MM, Banerjee T, Singh RS. Size-segregated characteristics of bioaerosols during foggy and non-foggy days of winter, meteorological implications, and health risk assessment. *Environmental Science: Advances*. 2024;3(8):1163-72.
3. Vishwakarma YK, Ram K, Gogoi MM, Banerjee T, Singh RS. Size-segregated bioaerosols concentration and characterization under diverse microenvironments. *Air Quality, Atmosphere & Health*. 2025 Feb;18(2):521-35.
4. Vishwakarma YK, Gogoi MM, Babu SN, Singh RS. How dominant the load of bioaerosols in PM_{2.5} and PM₁₀: a comprehensive study in the IGP during winter. *Environmental Science and Pollution Research*. 2023 Nov;30(52):112277-89.
5. Vishwakarma YK, Shahi A, Singh RS. Effect of indoor bioaerosols (fungal) exposure on the health of Post-COVID-19 patients and possible mitigation strategies. *COVID*. 2022 Jul 11;2(7):940-51.
6. Vishwakarma YK, Tiwari S, Mohan D, Singh RS. A review on health impacts, monitoring and mitigation strategies of arsenic compounds present in air. *Cleaner Engineering and Technology*. 2021 Jul 1;3:100115.
7. Singh A, Vishwakarma YK, Mayank, Bhardwaj N, Singh RS. Antimicrobial Resistance: Introduction and Challenges. In *Microbial Biocontrol Techniques: Importance in Ensuring Food Security 2025* Jan 21 (pp. 293-309). Singapore: Springer Nature Singapore.