South Asian Journal of Research in Microbiology

Volume 18, Issue 5, Page 1-17, 2024; Article no.SAJRM.114071
ISSN: 2582-1989

Microbial Prevalence in Soil Water in the River Deltas of the World

Rajrupa Ghosh [a++*] and Rituparna Acharya [b++]

[a] Institute of Management Study, Affiliated to MAKAUT, Department of Allied and Health Science, E.M Bypass, 93 Mukundapur main road, West Bengal, Kolkata-700099, India.
[b] Netaji Subhas Open University, DD-26, Sector-I, Salt Lake City, West Bengal, Kolkata-700064, India.

Authors' contributions

This work was carried out in collaboration both authors. There are two authors who are solely owners of the content of the manuscript. Author RA was the creator of the idea and the main guide of this reviewed article. Author RG was the corresponding author and contributor who collected and formulated all the information from different published article. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/SAJRM/2024/v18i5358

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114071

Review Article

Received: 03/02/2024
Accepted: 06/04/2024
Published: 10/04/2024

ABSTRACT

There is a wide range of diverse soil and aquatic microbes reside in different deltas of the world that mainly exhibit in various forms such as bacteria, fungi, parasites, archaeans, actinomycetes, virus etc. They contribute to the environment in various ways to maintain the balance of natural elements, bio geological components and also help in protecting the ecological components. Microbes that are living in the soil provide plants along with environmental and natural protection from diseases and pests. They are very much essential for transforming nitrogen and nutrients into the forms that is consumable for plants. Decomposition, production of Oxygen, evolution, as well as symbiosis are the vital roles that are played by different soil and aquatic microbes. Some river deltas show maximum populations of saline soil dependent bacterial and fungal community, where as some river deltas are enriched with some specific microbes that are

[++] Assistant Professor;
**Corresponding author: Email: riku.rock93@gmail.com;*

responsible for soil remediation. In some cases some species of hydrocarbon degrading microorganisms contribute to differences in C, N, P ratios. As the microbes are also responsible for producing different antigens as well as allergens that are mainly causative agents for varying infectious diseases, in need of its curative drugs and antibiotic medicines some microbes are involved in research studies for production of medicinal drugs and anti-allergens.

Keywords: Microbes; decomposition; hydrocarbon; parasites; fungi; causative agents; antibiotics; drugs.

1. INTRODUCTION

A delta of a river is just like a form of land which is created by the filtration, sedimentation and the depositions of solid particles by the flow of river. It is mainly formed by the slow river action that is always observed where the river or stream ends up or meets up to the ocean or lake or estuary or any other stream or water body [1]. At the lower course of the river as the wave action and carrying capacity of solid particles of the stream becomes diminished, the maximum sedimentations as well as the depositions have been created and that contributes to the production of a land form of alluvium called delta. These deltoid land forms are enriched with nutrients like nitrogen, phosphorous, calcium, silicon, ammonia, nitrate, phosphate, sulfate and huge amount of organic compounds including oxygen and hydrocarbons. The accumulation of these nutrients occurs through the siltation process which helps large diversity of microbes to grow on along with food web and also provides as large habitat of microbes.

Microbes or the microorganisms are mainly unicellular organisms. But they possess diverse form of domains—Archaea, bacteria and eukaryota. Among them archaea and bacteria are unicellular while the eukaryote represents multi cellular organisms. Besides the protozoans, fungi and actinomycetes are also considered as the microorganisms. In the river deltas the microorganisms mainly reside in the soil and in the water. So they are classified as soil microbes and aquatic microbes. The soil microbes which are functional, are always embedded with silts or alluvium that is organic in nature. And soil microorganisms act in integrated way to hold nutrients into the soil and transfer them in nutrient locked in soil, such as nitrogen fixation etc [2-4]. Such microorganisms reside on the surface soil as well as on the subsurface with the depth ranging from some hundreds to thousand kilometers or meters inside the ground. As the soil depth increases, the number of microbes residing in soil also declines. And that is due to the decline of organic compounds which is rich in the surface and subsurface portion rather than the depths. So they play an important role to maintain the composition of the soil profile [5-9]. The rhizosphere or the plant root region of the soil harbors maximum population of microorganisms than the other regions of soil as the rhizosphere is rich in nutrients. The prokaryotic microorganisms possess the width of 0.5-1 mm and length of at least 2 mm. Inspite of varying shapes of bacteria such as rod, comma, filamentous, spiral, spherical, the most available form is short sized rod shaped bacteria that is coccoid rods. The mostly available forms of bacterial genera found in soil are *Bacillus, Pseudomonas, Arthrobacter, Agrobacterium, Clostridium, Alcaligenes, Flavobacterium, Micrococcus, Corynebacterium, Mycobacterium*, and *Xanthomonas*. Aerobic bacteria undergoes direct respiration in the air with presence of Oxygen as electron acceptor, whereas anaerobic bacteria undergoes fermentation or indirect respiration with ferric ion, nitrate, sulfate, carbonate and organic compounds as alternative electron acceptors [10-12]. The deltoid soil that is heavily compacted or waterlogged is rich in anaerobic bacteria than the aerobic populations. Besides the carbon-nitrogen ratio and pH in the soil also contribute to the soil microbial population and diversity [13-19].

Apart from this fungi also constitute a huge biomass in soil of all soil microorganisms. They belong to three groups like decomposers, fungi with mutual relations such as mycorrhyza and pathogenic fungi. These include *Tricholoma, Amanita, Descomyces, Torrendia, Thelephora, Phytophthora, Verticillium, Pythium* and *Rhizoctonia* [20-25]. Besides some actinomycetes or filamentous bacteria that are either gram positive or gram negative which are abundant in neutral or alkaline pH and form extensive mycelia or colonies. These are *Streptomyces, Thermoactinomycetes, Micromonospora,* and *Nocardia.* Apart from

these the soil microorganisms include yeast, algae, some free living or colonial protozoa such as flagellates, ciliates and amoeba. Others are blue-green algae or cyanobacteria which are phototrophic mostly found where water and light is abundant in the river deltas [26-28]. These play a role mainly in nitrogen fixation in the absence of O_2. These include *Nostoc, Anabaena, Nodularia*, *Prochlorothrix,* etc [29-30].

There is a wide variety of aquatic bacteria reside in the river delta such as *Vibrio cholerae, Vibrio parahaemolyticus, Salmone,lla typhi, Salmonella paratyphi, Salmonella enteric, Shigella dysenteriae, Shigella flexneri, Shigella boydii, Shigella sonnei, Escherichia coli* [31-37] *etc.* Other aquatic microbes also include cyanobacteria, protozoa, fungi, algae, archaea etc. The fresh water of streams and rivers having high velocity, consists of higher oxygen content that provides a large habitat of aquatic microorganisms. Besides a lot of organic compounds are accumulated here in the water body from the bank runoff and sediments that provide as food source of species.

There are a huge numbers of river deltas present in the world that harbor diverse types of microorganisms in the soil and in the river water. Such deltas include Pearl, Yangtze, Yellow, Red, Irrawaddy, Mekong, Ganges-Brahmaputra, and Indus [38-40].

2. SOIL MICROBES

2.1 Yellow River Delta

A research paper shows that some river delta like yellow river delta of China possess saline soil that undergoes different enzyme activities through microbial community residing the saline soil along with the halophyte plant communities such as *Phragmites australis, Suaeda salsa, and Tamarix chinensis.* The microbial composition and salinity of the soil enhances the enzymatic functions. Such as catalase that influence the redox potential, dehydrogenase, protease, urease that maintain the carbon and nitrogen cycle respectively. In this river delta the process of succession from herb community to woody plant community along with various mechanisms of salt tolerance a large biomass of soil environment influence the diversity of microbial growth as well as the enzymatic actions [41-44].

An important study on Yellow river delta also demonstrates how the potentiality of indigenous soil bacterial remediation has been used as broad way treatment for soil remediation. Here as the soil contaminators the petroleum hydrocarbon degrading microbes are identified and showed how the pH, salinity, optimal temperature, proportional ratio of C,N,P in the soil influence the degradation of polyaromatic hydrocarbons, n-alkanes, crude oil, diesel oil etc. with the help of these microorganisms [41, 44-49].

2.2 Yangtze River Delta

Another study of Yangtze River delta of China reveals that how the tidal wetland soil is transformed to a paddy field that involves the diverse microbial community. The continuous paddy cultivation and reclamation of wetland ecosystem impacts on microbial population, especially the succession process in deltoid soil. This pattern of succession is analyzed by using gene pyrosequencing of 16s rRNA. The result showed the abundance decrease of *Planctomycetes* and .*Gammaproteobacteria* and increase in number of *Firmicutes* and *Alphaproteobacteria*. The further research work discloses that rice cultivation with a long time period also enhances the growth of *Rhodospirillaceae* and *Clostridiaceae* which are intensely beneficial to huge paddy yielding at once. This predominantly changes the physiochemical properties of the soil, redox potential capacity of ion exchange and the pH level [50].

2.3 Colorado River Delta

Again a study on Colorado River basin delta represents that siltation of sandstones and fine grained clay substances constitute the rocky soil composition of this delta. The detritus growth on drainage river basin dominates calcite, quartz and subordinate dolomites including plagioclase, illite, kaolinite, zircon, magnetite, clinozoisite, leucoxene, chlorite and biotite [51-54].

2.4 Mississippi River Delta

Some studies on nitrogen fixation by microbes on river deltas and estuary deliver that river sediment N_2 fixation rate is lower than the N_2 cycling process due to fixation inhibition by potentially excessive concentration of Dissolved Inorganic N_2 (DIN) among the sediments that are bioavailable. These are mediated by Cyanobacteria, chemolithotrophs or

photosynthetic bacteria, methanogens, different heterotrophs or sulfate reducers. This fixation occurs by the conversion from N_2 to Ammonia (NH_3) through production of nitrates and nitrites via different phases of chemical reactions [55-60].Some studies show that *Myrica gale* contributes 3 to 4 g N m^{-2} yr^{-1} through N_2 fixation to the *Sphagnum* bogs. That are common in the wetland ecosystem of river deltas. And here important role is played by some anaerobic, aerobic, nonsymbiotic and few blue-green algae. Thus the physiochemical changes in soil develop high acidic pH and lower nutrients availability [61-62].

2.5 Lena River Delta

Another study of Lena river delta demonstrates that the analysis of suspended particles, soil, dissolved organic and inorganic Nitrogen content along with ^{15}N isotope comprise to generate inventory of N_2. The study shows that the N_2 content in the soil is contributed by N_2 fixation from atmosphere by several microbes including planktons in the form of nitrates, later transported from the delta to the sea or water body in the form of dissolved organic nitrogen (DON), especially in the winter season and that is also in higher rate (approx. 10 µmol/L). In the season of summer, N_2 is transported in the form of DON and nitrogen particulate matter in the suspension where the amount of nitrate is less than 1µmol/L. Not only nitrogen but also different turnover of carbon, methane, methanotropic community and other substances have been seen that all are influence greatly by the soil microbes [63-72].

2.6 Volga River Delta

A study of Volga river delta demonstrates that the biomass and the quantity of microbial community at the upper portion of humus horizon is inferred in the alluvial type of soil which includes calcareous soddy desertified soil, mucky gley, and dark hydro metamorphic humus soil. Algal cells and fungal mycelium are also abundant in the microbial biomass of the deltoid soil that ranges between 35%-47%. The prokaryotic microbial populations also determined as 2-6%, and the carbon amount as 1.4-2.3% in the soil as organic matter, especially in the spring season. The organic composition of the alluvial soil is characterized by high concentration of microbial mineral coefficient as well as oligotrophy [73-75].

2.7 Madagascar River Delta

Another study on Madagascar river delta (Alaotra basin, red and other rivers of Madagascar) demonstrates how the climatic changes become the leading influencing factors for the microbial diversity in the deltoid soil. Temperature, humidity, rain fall effect the physiochemical composition of the soil including the organic matters and the mineralization. The stoichiometric decomposition exerts the prime effect that is boosted in the cold climate and that is due to less organic compound in soil along with fast growing microbial population. In contrast, the mining of the nutrient coefficients also influenced during warm environment as there is a loss of competition between slowly growing microbial population for mining organic compounds and fast growing population for the purpose of energy rich components in the soil [76-79].

2.8 Danube River Delta

A research work on Danube river delta demonstrates the soil fungi community as abundant microbial population of the delta that influences its ecosystem and biodiversity. Almost seven different areas were studied to make a comparison on fungal community. The study also focuses on the effect of microbial growth in the soil that results in the changes of soil texture, soil profile, soil humidity, depth of sandy gravel components, ground water level, plant community as well as the other organic composition of the soil [80-88].

2.9 Ganga-Brahmaputra-Meghna delta (GBM)

Being the largest river delta of the world GBM river delta inhabits a huge population of biodiversity and impacts widely on the socio-economic field of the world. As the delta is maximally composed of alluvial soil of the flooded plain made up of river deposition and siltation, the organic constituents along with different microbes including bacteria, fungi, parasites, helminthes, virus play an important role for the cultivation of different vegetations in the soil [89]. The maximal humid situation of upstream in comparison to the downstream provides variations in the fungi pollens that also changes the physio-chemical soil texture for a long time period [90-106]. Sundarban river delta is also an example of this largest deltoid soil microbial activity [104, 107-121].

2.10 Mekong River Delta

Another study of Mekong river delta of Vietnam demonstrates about the fecal pollutants like *streptococcus*, *E.coli*, *coliform* bacteria that are also called as indicator bacteria. The study assessed the soil decompositions of these microbes in temperate and tropical region of the delta and concluded that the *E.coli* population in summer is always higher than the winter population in soil [122-132].

2.11 Indus River Delta

A different research work of Indus river delta of Pakistan, the study is focused on the 3 different tidal creeks which include Gharo, Phitti, Isaro creek for assessing the soil carbon flux that is mediated by bacteria in the ecosystem. During the study the bacterial carbon production, bacterial biomass, especially the primary productivity is measured to conclude he bacterial growth with other different organic substances like Phosphorus, Nitrogen, and Hydrogen along with carbon. The study also focuses on the mangrove community growth with organic matter that indicates the destruction of mangrove ecosystem with organic compounds in soil always leads to the negative or reduced development of the ecosystem structure and function indulging less production of sea fish and shrimps [133-145].

2.12 Krishna River Delta

Some studies of Krishna river delta of the Peninsular India proposes the C/N ratio of the deltaic soil that is varied by the flood created by the heavy rain fall along with the release of the water from the dams of that region. And this C/N ratio also varies by the influences of different inhabited microbial decomposition of the soil. Not only that it is also assessed that the different organic debris also indulge in the C/N ratio of the deltaic soil that is influenced by the seasonal and non-seasonal flooding [146-151].

2.13 Mahanadi River Delta

An important study on Mahanadi river delta shows that some soil bacteria such as *Serratia sp***.** that is isolated from the mangrove deltaic soil has phosphate solubilizing function along with phosphatase activity that helps in growth and development of soil decomposition [106,152-155].

3. AQUATIC MICROBES

3.1 Yellow River Delta

A study on coastal microbial community and its ecological balance represents that a vast investigation on different tidal regions such as subtidal, intratidal and supratidal flat postulates diverse microbial population. This is experimented throughout four seasons of a year [156] by using 16s rRNA gene with PGM platform of Ion Torrent [44, 157-160].

3.2 Yangtze River Delta

In an efficient research work on microbial planktonic composition on Yangtze River an assessment is done to evaluate the changes in water quality and dynamics along with its flow pattern. This is corresponded with RNA and DNA based 16S rRNA gene phylogenies over consecutive three different seasons. Different clone and cDNA libraries are prepared [161-166].

3.3 Colorado River Delta

Another study represents the effect of pre and post flood on the dynamics of carbon cycling over the dry Colorado River water flow. This also affect the microbial diversity and population in the aquatic environment. Human approaches of aquatic resources continues to increase, the series of dehydrating and hydrating of natural riverbeds as well as deltas that may predominantly alter the total processing as well as storage of carbon within the system [167-170].

3.4 Mississippi River Delta

The study of Olivia Masson et al, represents the different microbial diversity and population which varies along with the salinity change in the river water. The assessment in the surface sector of the water body demonstrates the actinobacteria and proteobacteria whereas the deeper region of the water demonstrates the Thaumarchaeota [171].

3.5 Lena River Delta

Another study of Lena River focuses on different enzymatic bacterial activities and their production. Determination of different organic matter that is recycling and preserving along with the organic carbon production, is done in this research work. Besides these are transported

from continent to the ocean, and also sequestrated in the arctic environmental ecosystem [172].

3.6 Volga River Delta

A different study of Volga river delta represents how enterobacterial halotolerance is isolated from aquatic fish and water sample, and assessed through meat peptone broth culture including 3, 7 as well as 10% sodium chloride incubating at 37^0 c. The assessment also demonstrates the bacterial specific classifications such as they are in proteus group, citrobacteria or enterobacteria [173].

3.7 Danube River Delta

Another study on Danube river delta reveals that different enterobacteria, parasites, fungi etc. from fecal pollutants in the river fresh water give birth to maximum health hazards of river fauna as well as the human residence of the river delta. A detailed assessment of river fresh water and its different branches reveals that the potential indicator bacteria of aquatic pollution is Escherichia coli and intestinal enterococci for fecal pollutants [84, 174-175].

3.8 Ganga-Brahmaputra-Meghna delta (GBM)

A research study on the largest mangrove and river delta of the world that is GBM encapsulates the prevalence, differential activities and interactions of different water born microbes. Sedimentation and siltation influences the microbial growth including bacteria, parasites and fungi. The study also focuses on the climate change activities of the river delta that plays a leading role in enhancing the bacterial growth in water source. The microbial population also changes the salinity and other water organic composition that effects the further biotic and abiotic processes [98]. Some study identifies about marine anti-cancerous alkaloids that are extracted from some aquatic fungi, cyanobacteria, sponges, algae and tunicates [176-177].

3.9 Mekong River Delta

A vital research on the indicator bacteria of Mekong river delta depicts the relationship between the indicators as well as the chemical indicator microbes. Water sample is collected in different seasons throughout the year for further assessment and as a result it is determined that *E.coli* concentrations show higher and stronger logarithmic correlations along with coprostanols [122-123, 178-183].

3.10 Indus River Delta

An important study depicts that microbes of Indus river delta not only serve for biosphere creator but also provides sources for biotechnological vital valuable components and products. They help in destroying the pollutants, influence the global climatic changes, help to treat the anthropogenic wastes. They produce enzymes, medicinal drugs and compounds, anti-tumor agents, immune-suppressants, insecticides, anti-microbial agents, vitamins etc [119,130,184-187].

3.11 Krishna River Delta

As Krishna River faces different issues regarding sufficient water availability, various researches are being done and water linking projects are also going on. In this research study water sample has been taken from five different sectors of the river delta and various water qualitative assessments have been done, such as pH, calcium hardness, total hardness, sulphate, nitrate, nitrite, ammonia content analysis etc. It has been found that after utilizing water linking strategy when Godavari river enters in the Krishna river, then the water quality along with its pH and mineral contents also changed into different level that influences different microbial population growth and diversity [183-193].

3.12 Mahanadi River Delta

Again a study on Mahanadi river delta postulates that the aquifers of the river delta involves mixing of fresh water and coastal ground water at layer wise which enhances the microbial population habitat and its growth. The interface depth that ranges between 10-120 m including fresh river water aquifers on the surface underlain by brackish and saline water aquifers [105,153,194-201].

4. CONCLUSION

Being an important part of the biodiversity and environment, microbes show their different activities, and prevalence in different river delta's worldwide. Some deltas show different antibiotic activities as well as antimicrobial resistance activities. Some provides bioactive potential

compounds that helps in producing potential drugs and medicines that helps in recovering various infectious diseases as well as protecting human health. Some microbial species populations help in nitrogen fixation as well as increase the other organic and inorganic compounds and ionic composition that enrich the soil content enhancing the growth of vegetation and its cultivation. Deltoid microbes also provide applications in food industry for producing various food products. Not only for bioactive molecule production but also they contribute in maintaining bio-geological cycles of different natural elements and enrich the biodiversity and ecological environment. Besides changes in climate, bio-geological factors also alters the microbial species composition in soil and in water that leads to further modifications in biological and ecological activities.

Microorganisms can act as suppliers of ecosystem services that are vital to the nature and also to the human life and their activity. Enzymes of different Arctic bacterial body whose physiology has been adapted to extreme cold temperatures and also therefore it has enzymes that have various potential industrial utility, such as during the sustainable technical and industrial bio-food processing as well as during washing the specific powders that act very efficiently at energy or power saving very low washing temperatures. Interactions between micro-organisms that is inter-microbial interactions and between micro-organisms and plants that is intra microbial ineractions which can enrich people's understanding of utilization of environment's useful microbiological resources so that they can fight against plant pathogens. They also play as good bioindicators for microbes that destruct the food and food products under storage as well as refrigerated conditions or volatile metabolites.

ACKNOWLEDGEMENT

I would like to acknowledge my sincere gratitude to my colleagues, my Guide Dr. Rituparna Acharya and other associates of the department to help me in progress of this article. Lastly, I would like to express my heartfelt gratitude to my family members and friends who have provided lots of encouragement during the phases of this endeavor.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bhattacharya JP, Giosan L. Wave-influenced deltas: Geomorphological implications for facies reconstruction. Sedimentology.2003; 50(1):187-210.
2. Li M, Cao H, Hong Y, Gu JD. Using the variation of anammox bacteria community structures as a bio-indicator for anthropogenic/terrestrial nitrogen inputs in the Pearl River Delta (PRD). Applied Microbiology and Biotechnology. 2013;97(22):9875-83. PubMed PMID: 23728276. Epub 2013/06/04. eng.
3. Li M, Hong YG, Cao HL, Gu JD. Mangrove trees affect the community structure and distribution of anammox bacteria at an anthropogenic-polluted mangrove in the Pearl River Delta reflected by 16S rRNA and hydrazine oxidoreductase (HZO) encoding gene analyses. Ecotoxicology (London, England). 2011;20(8):1780-90. PubMed PMID: 21735127. Pubmed Central PMCID: PMC3195777. Epub 2011/07/08. eng.
4. Iriberri J, Ayo B, Artolozaga I, Barcina I. Grazing on allochthonous vs autochthonous bacteria in river water. Letters in Applied Microbiology. 1994; 18(1):12-4.
5. Nema V. Chapter 34 - The role and future possibilities of next-generation sequencing in studying microbial diversity. In: Das S, Dash HR, editors. Microbial Diversity in the Genomic Era: Academic Press; 2019;611-30.
6. Pandey A, Tripathi A, Srivastava P, Choudhary KK, Dikshit A. 1 - Plant growth-promoting microorganisms in sustainable agriculture. In: Kumar A, Singh AK, Choudhary KK, editors. Role of plant growth promoting microorganisms in sustainable agriculture and nanotechnology: Woodhead Publishing; 2019;1-19.
7. Lin ZQ. Volatalization. In: Jørgensen SE, Fath BD, editors. Encyclopedia of ecology. Oxford: Academic Press. 2008;3700-5.
8. Dazzo FB, Ganter S. Rhizosphere. In: Schaechter M, editor. Encyclopedia of Microbiology (Third Edition). Oxford: Academic Press. 2009;335-49.
9. Kennedy AC, de Luna LZ. Rhizosphere. In: Hillel D, editor. Encyclopedia of Soils in the

Environment. Oxford: Elsevier. 2005;399-406.
10. Kracke F, Vassilev I, Krömer JO. Microbial electron transport and energy conservation – the foundation for optimizing bioelectrochemical systems. Frontiers in Microbiology. English. 2015;11;6.
11. Ucar D, Zhang Y, Angelidaki I. An overview of electron acceptors in microbial fuel cells. Frontiers in Microbiology. English. 2017;19;8.
12. Bhunia P. 3.4 - Fundamentals of biological treatment. In: Ahuja S, editor. Comprehensive Water Quality and Purification. Waltham: Elsevier; 2014;47-73.
13. Barton IS, Fuqua C, Platt TG. Ecological and evolutionary dynamics of a model facultative pathogen: Agrobacterium and crown gall disease of plants. Environmental microbiology. 2018;20 (1):16-29.
PubMed PMID: 29105274.
Pubmed Central PMCID: PMC5764771. Epub 2017/11/07. eng.
14. Clark DP, Pazdernik NJ, McGehee MR. Chapter 19 - Noncoding RNA. In: Clark DP, Pazdernik NJ, McGehee MR, editors. Molecular Biology (Third Edition): Academic Cell. 2019;604-21.
15. Cole LA. Chapter 13 - Evolution of chemical, prokaryotic, and eukaryotic life. In: Cole LA, editor. Biology of Life: Academic Press. 2016;93-9.
16. Oren A. 19 - How to name new genera and species of Prokaryotes? In: Rainey F, Oren A, editors. Methods in Microbiology. 38: Academic Press. 2011;4 37-63.
17. Parker J. Bacteria. In: Brenner S, Miller JH, editors. Encyclopedia of Genetics. New York: Academic Press. 2001;146-5 1.
18. Karls AC. Alternation of Gene Expression. In: Maloy S, Hughes K, editors. Brenner's Encyclopedia of Genetics (Second Edition). San Diego: Academic Press. 2013;92-6.
19. Johnson DB, Aguilera A. Extremophiles and acidic environments. In: Schmidt TM, editor. Encyclopedia of microbiology (Fourth Edition). Oxford: Academic Press. 2019;206-27.
20. Feder F, Oliver R, Rakotoarisoa J, Muller B, Scopel E. Geochemical Properties of Variable Charge Soil Explain the Low Nitrogen Bioavailability. Communications in Soil Science and Plant Analysis. 2020 2020/08/21;51(15):2022-37.
21. Megonigal JP, Hines ME, Visscher PT. 10.8 - Anaerobic Metabolism: Linkages to Trace gases and aerobic processes. In: Holland HD, Turekian KK, editors. Treatise on Geochemistry (Second Edition). Oxford: Elsevier. 2014;273-359.
22. Glassman SI, Weihe C, Li J, Albright MBN, Looby CI, Martiny AC, et al. Decomposition responses to climate depend on microbial community composition. Proceedings of the National Academy of Sciences. 2018;115(47):11994-9.
23. Morris LA. SOIL BIOLOGY AND TREE GROWTH | Soil Organic Matter Forms and Functions. In: Burley J, editor. Encyclopedia of forest sciences. Oxford: Elsevier. 2004;1201-7.
24. Dlugokencky E, Houweling S. METHANE. In: Holton JR, editor. Encyclopedia of Atmospheric sciences. Oxford: Academic Press. 2003;1286-94.
25. Schowalter TD. Chapter 14 - Decomposition and pedogenesis. In: Schowalter TD, editor. Insect Ecology (Fourth Edition): Academic Press. 2016;477-510.
26. Dorokhova MF, Kosheleva NE, Terskaya EV. Algae and cyanobacteria in soils of Moscow. American Journal of Plant Sciences. 2015;06(15):11.
27. Haynes RJ. Chapter Two - Nature of the belowground ecosystem and its development during pedogenesis. In: Sparks D, editor. Advances in Agronomy. 127: Academic Press. 2014;43-109.
28. Pajares S, Bohannan BJM. Ecology of Nitrogen Fixing, Nitrifying, and Denitrifying Microorganisms in Tropical Forest Soils. Frontiers in Microbiology. English. 2016;7.
29. Anthelme F, Grossi JL, Brun JJ, Didier L. Consequences of green alder expansion on vegetation changes and arthropod communities removal in the northern French Alps. Forest Ecology and Management. 2001 2001/05/01/;145(1):57-65.
30. Wantzen KM, Yule CM, Mathooko JM, Pringle CM. 3 - Organic Matter Processing in Tropical Streams. In: Dudgeon D, editor. Tropical Stream Ecology. London: Academic Press. 2008;43-64.
31. Cabral JP. Water microbiology. Bacterial pathogens and water. International Journal of Environmental Research and Public

Health. 2010;7(10):3657-703.
PubMed PMID: 21139855.
Pubmed Central PMCID: PMC2996186. Epub 2010/12/09. eng.

32. Irrgang A, Roschanski N, Tenhagen B-A, Grobbel M, Skladnikiewicz-Ziemer T, Thomas K, et al. Prevalence of mcr-1 in E. coli from livestock and food in Germany, 2010–2015. PloS one. 2016; 11(7):e0159863.
33. Saxena T, Kaushik P, Krishna Mohan M. Prevalence of *E. coli* O157:H7 in water sources: An overview on associated diseases, outbreaks and detection methods. Diagnostic Microbiology and Infectious Disease. 2015/07/01/;82(3): 249-64.
34. Ogden ID, MacRae M, Strachan NJC. Is the prevalence and shedding concentrations of E. coli O157 in beef cattle in Scotland seasonal? FEMS Microbiology Letters. 2004;233(2):297-300.
35. Laegreid W, Elder R, Keen J. Prevalence of Escherichia coli O157: H7 in range beef calves at weaning. Epidemiology & Infection. 1999;123(2):291-8.
36. Olesen B, Hansen DS, Nilsson F, Frimodt-Møller J, Leihof RF, Struve C, et al. Prevalence and characteristics of the epidemic multiresistant *Escherichia coli* ST131 clonal group among extended-spectrum beta-lactamase-producing *E. coli* Isolates in Copenhagen, Denmark. Journal of Clinical Microbiology. 2013;51(6):1779-85.
37. Franz E, Klerks MM, Vos OJD, Termorshuizen AJ, Bruggen AHCv. Prevalence of Shiga Toxin-Producing Escherichia coli stx₁, stx₂, eaeA, and rfbE Genes and Survival of E. coli O157:H7 in Manure from organic and low-input conventional dairy farms. Applied and Environmental Microbiology. 2007;73(7):2180-90.
38. Seto KC. Exploring the dynamics of migration to mega-delta cities in Asia and Africa: Contemporary drivers and future scenarios. Global Environmental Change. 2011 2011/12/01/;21:S94-S107.
39. Darby SE, Hackney CR, Leyland J, Kummu M, Lauri H, Parsons DR, et al. Fluvial sediment supply to a mega-delta reduced by shifting tropical-cyclone activity. Nature. 2016 539(7628):276-9.
PubMed PMID: 27760114. Epub 2016/11/04. eng.
40. Taneja N, Mewara A. Shigellosis: Epidemiology in India. The Indian Journal of Medical Research. 2016;143(5):565-76.
PubMed PMID: 27487999. Pubmed Central PMCID: PMC4989829. Epub 2016/08/05. eng.
41. Cao D, Shi F, Koike T, Lu Z, Sun J. Halophyte Plant Communities affecting enzyme activity and microbes in saline soils of the Yellow River Delta in China. CLEAN – Soil, Air, Water. 2014;42(10):1433-40.
42. Kuang S, Su Y, Wang H, Yu W, Lang Q, Matangi R. Soil Microbial Community structure and diversity around the aging oil sludge in Yellow River Delta as Determined by High-Throughput Sequencing. Archaea. 2018/08/30;2018: 7861805.
43. Liu F, Mo X, Kong W, Song Y. Soil bacterial diversity, structure, and function of Suaeda salsa in rhizosphere and non-rhizosphere soils in various habitats in the Yellow River Delta, China. Science of The Total Environment. 2020/10/20/;740:140144.
44. Wang Z-Y, Xin Y-Z, Gao D-M, Li F-M, Morgan J, Xing B-S. Microbial community characteristics in a degraded wetland of the Yellow River Delta. Pedosphere. 2010/08/01/;20(4):466-78.
45. Pei Y, Yu Z, Ji J, Khan A, Li X. Microbial community structure and function indicate the severity of chromium contamination of the Yellow River. Frontiers in Microbiology. English. 2018;9.
46. Wu T, Li XB, Xu J, Liu LX, Ren LL, Dong B, et al. Diversity and functional characteristics of endophytic bacteria from two grass species growing on an oil-contaminated site in the Yellow River Delta, China. The Science of the Total Environment. 2021;767:144340.
PubMed PMID: 33429273.
Epub 2021/01/12. eng.
47. Zhao GM, Ye SY, Xin YZ, Ding XG, Yuan HM, Wang J. Study on microbial community characteristics in the Northern Wetland Reserve Area of the Modern Yellow River Delta. Advanced Materials Research. 2013;726-731:463-9.
48. Xia N, Xia X, Liu T, Hu L, Zhu B, Zhang X, et al. Characteristics of bacterial community in the water and surface sediment of the Yellow River, China, the largest turbid river in the world. Journal of

Soils and Sediments. 2014/11/01;14(11): 1894-904.
49. Dong X, Yang L, Harbo LS, Yan X, Chen J, Zhao C, et al. Effects of land use on soil microbial community structure and diversity in the Yellow River floodplain. Journal of Plant Ecology. 2022:rtac075.
50. Ding L-J, Su J-Q, Li H, Zhu Y-G, Cao Z-H. Bacterial succession along a long-term chronosequence of paddy soil in the Yangtze River Delta, China. Soil Biology and Biochemistry. 2017/01/01/;104:59-67.
51. Muffler LJP, Doe BR. Composition and mean age of detritus of the Colorado River delta in the Salton Trough, southeastern California. Journal of Sedimentary Research. 1968;38:384-99.
52. Gilbert RG, Nakayama FS, Bucks DA, French OF, Adamson KC, Johnson RM. Trickle irrigation: Predominant bacteria in treated Colorado River water and biologically clogged emitters. Irrigation Science. 1982/01/01;3(2):123-32.
53. Tunnicliff B, Brickler SK. Recreational water quality analyses of the Colorado River corridor in Grand Canyon. Applied and Environmental Microbiology. 1984;48 (5):909-17.
PubMed PMID: 6508305. Pubmed Central PMCID: PMC241650. Epub 1984/11/01. eng.
54. Hamner S, Fenster SD, Nance BT, McLain KA, Parrish-Larson KS, Morrow MW, et al. Unexpected Prevalence of eae-Positive Escherichia coli in the Animas River, Durango, Colorado. International Journal of Environmental Research and Public Health. 2019;17(1).
PubMed PMID: 31892143. Pubmed Central PMCID: PMC6981472. Epub 2020/01/02. eng.
55. Geisler E, Bogler A, Bar-Zeev E, Rahav E. Heterotrophic nitrogen fixation at the hyper-eutrophic qishon river and estuary system. Frontiers in Microbiology. English. 2020;11.
56. Gruber N. Chapter 1 - The marine nitrogen cycle: Overview and challenges. In: Capone DG, Bronk DA, Mulholland MR, Carpenter EJ, editors. Nitrogen in the Marine Environment (Second Edition). San Diego: Academic Press. 2008;1-50.
57. Marino RW, Howarth R. Nitrogen Fixation in Freshwater and Saline Waters☆. Reference Module in Earth Systems and Environmental Sciences: Elsevier; 2014.
58. Marino R, Howarth RW. Nitrogen Fixation☆. In: Mehner T, Tockner K, editors. Encyclopedia of Inland Waters (Second Edition). Oxford: Elsevier; 2022; 163-70.
59. Joye SB, Anderson IC. Chapter 19 - Nitrogen Cycling in Coastal Sediments. In: Capone DG, Bronk DA, Mulholland MR, Carpenter EJ, editors. Nitrogen in the Marine Environment (Second Edition). San Diego: Academic Press. 2008;867-915.
60. Coyne MS, Frye WW. NITROGEN IN SOILS | Cycle. In: Hillel D, editor. Encyclopedia of soils in the environment. Oxford: Elsevier; 2005;13-21.
61. Bedford BL, Leopold DJ, Gibbs JP. Wetlands Ecosystems. In: Levin SA, editor. Encyclopedia of Biodiversity. New York: Elsevier. 2001;781-804.
62. Li S, Twilley RR, Hou A. Heterotrophic nitrogen fixation in response to nitrate loading and sediment organic matter in an emerging coastal deltaic floodplain within the Mississippi River Delta plain. Limnology and Oceanography. 2021;66(5): 1961-78.
63. Szpak P, White CD, Longstaffe FJ, Millaire JF, Vásquez Sánchez VF. Carbon and nitrogen isotopic survey of Northern peruvian plants: baselines for paleodietary and paleoecological studies. PloS One. 2013;8(1):e53763.
PubMed PMID: 23341996. Pubmed Central PMCID: PMC3547067. Epub 2013/01/24. eng.
64. Sanders T, Fiencke C, Fuchs M, Haugk C, Juhls B, Mollenhauer G, et al. Seasonal nitrogen fluxes of the Lena River Delta. Ambio. 2022 2022/02/01;51(2):423-38.
65. Polyakov V, Orlova K, Abakumov E. Soils of the Lena River Delta, Yakutia, Russia: Diversity, characteristics and humic acids molecular composition. Polarforschung. 2018 01/01;88:135-50.
66. Polyakov V, Orlova K, Abakumov E. Landscape-dynamic aspects of soil formation in the Lena River Delta. Czech Polar Reports. 2018 07/01;8:260-74.
67. Igorevich Polyakov V, Ilych Alekseev I, Sergeevna Orlova K, Vasilevich Abakumov E, Kostecki J. Water holding capacity of Russian Arctic soils (Lena River Delta and Yamal Peninsula). Soil Sci Ann. 2020;71 (1):37-46.
68. Polyakov V, Abakumov E. Micromorphological Characteristic of Different-Aged Cryosols from the East Part of Lena River Delta, Siberia, Russia.

Geosciences. 2021;11(3):118.
PubMed PMID:
DOI: 10.3390/geosciences11030118

69. Prater I, Zubrzycki S, Zoor L, Mueller CW. Composition and state of decay of soil organic matter in permafrost-affected soils of the Lena River Delta, Arctic Russia. 2018;3436.
70. Sanders T, Fiencke C, Pfeiffer EM, editors. Small-Scale variability of dissolved inorganic Nitrogen (DIN), C/N ratios and ammonia oxidizing capacities in various permafrost affected soils of Samoylov Island, Lena River Delta, Northeast Siberia; 2010.
71. Wagner D, Kobabe S, Liebner S. Bacterial community structure and carbon turnover in permafrost-affected soils of the Lena Delta, northeastern SiberiaThis article is one of a selection of papers in the Special Issue on Polar and Alpine Microbiology. Canadian Journal of Microbiology. 2009;55(1):73-83.
72. Grodnitskaya ID, Trusova MY, Syrtsov SN, Koroban NV. Structure of microbial communities of peat soils in two bogs in Siberian tundra and forest zones. Microbiology. 2018/01/01;87(1):89-102.
73. Sal'nikova NA, Polyanskaya LM, Tyugai ZN, Sal'nikov AN, Egorov MA. Microbial communities of alluvial soils in the Volga River delta. Eurasian Soil Science. 2009/01/01;42(1):56-61.
74. Sal'Nikova NA, Polyanskaya LM, Tyugai Z, Sal'Nikov AL, Egorov ME. Microbial complexes of therapeutic mud from Lake Tinaki-1. Eurasian Soil Science. 2008; 41:1302-5.
75. Tkachenko A, Gerasimova M, Lychagin M. Subaquatic soils in the Volga, Don and Kuban Rivers deltas. 2015;15003.
76. Jiang X, Amelung W, Cade-Menun BJ, Bol R, Willbold S, Cao Z, et al. Soil organic phosphorus transformations during 2000 years of paddy-rice and non-paddy management in the Yangtze River Delta, China. Scientific Reports. 2017/09/07;7 (1):10818.
77. Pastor L, Brandily C, Schmidt S, Miramontes E, Péron M, Appéré D, et al. Modern sedimentation and geochemical imprints in sediments from the NW Madagascar margin. Marine Geology. 2020 2020/08/01/;426:106184.
78. Razanamahandry VF, Dewaele M, Govers G, Brosens L, Campforts B, Jacobs L, et al. Stable isotope profiles of soil organic carbon in forested and grassland landscapes in the Lake Alaotra basin (Madagascar): insights in past vegetation changes. Biogeosciences. 2022;19 (16):3825-41.
79. Razanamalala K, Razafimbelo T, Maron PA, Ranjard L, Chemidlin N, Lelièvre M, et al. Soil microbial diversity drives the priming effect along climate gradients: A case study in Madagascar. The ISME Journal. 2018;12(2):451-62.
PubMed PMID: 29039844. Pubmed Central PMCID: PMC5776458. Epub 2017/10/19. eng.
80. Simonovicova A, Mičuda R. Inland delta plant community structure and soil microscopic fungi on Kopac Island (Slovakia) after damming of Danube river. Polish Botanical Journal. 200812/30;53 :177-82.
81. Spinu M, Gurzau A, Șandru C, Gati G, Niculae M. Heavy metal pollutome and microbial resistome reciprocal interaction and its impact on human and animal matrices; 2018.
82. Saliot A, Parrish CC, Sadouni Nm, Bouloubassi I, Fillaux J, Cauwet G. Transport and fate of Danube Delta terrestrial organic matter in the Northwest Black Sea mixing zone. Marine Chemistry. 2002 2002/10/01/;79(3):243-59.
83. Halder J, Vystavna Y, Wassenaar LI. Nitrate sources and mixing in the Danube watershed: implications for transboundary river basin monitoring and management. Scientific Reports. 2022/02/ 09;12 (1):2150.
84. Snigirova A, Bogatova Y, Barinova S. Assessment of River-Sea Interaction in the Danube Nearshore Area (Ukraine) by Bioindicators and Statistical Mapping. Land. 2021;10(3):310.
PubMed PMID:
DOI:10.3390/land10030310
85. Winter C, Hein T, Kavka G, Mach RL, Farnleitner AH. Longitudinal changes in the bacterial community composition of the Danube River: A whole-river approach. Applied and Environmental Microbiology. 2007;73(2):421-31.
PubMed PMID: 17085708. Pubmed Central PMCID: PMC1796958. Epub 2006/11/07. eng.
86. Mikhailyuk TI, Vinogradova OM, Glaser K, Rybalka NA, Demchenko EM, Karsten U. Algae of biological soil crusts from sand dunes of the Danube Delta Biosphere

Reserve (Odesa Region, Ukraine). 2021-03-31;23(1):7-42.
87. Marina S, Anca Elena G, Carmen Dana Ș, Gabriel G, Mihaela N. Heavy metal pollutome and microbial resistome reciprocal interaction and its impact on human and animal matrices. In: Sara S, editor. Antibiotic Use in Animals. Rijeka: Intech Open. 2017;8.
88. Călugăr A. Soil mesostigmatid mites as a potential tool for bioindication concerning ecological status of forest. Acarologia. 2018-09-28;58(Suppl):18-24. Epub 2018-09-28.
89. Islam S. Deltaic floodplains development and wetland ecosystems management in the Ganges–Brahmaputra–Meghna Rivers Delta in Bangladesh. Sustainable Water Resources Management. 2016 09/01;2.
90. Kumar S, Rahman A, Thilakanayaka V, Khan MHR, Liu J, Islam GM. Modern alluvial pollen distribution in Ganges–Brahmaputra–Meghna (GBM) floodplain and its paleoenvironmental significance. Review of Palaeobotany and Palynology. 2019 05/03;267:1-16.
91. Borah L, Kalita B, Boro P, Kulnu AS, Hazarika N. Climate change impacts on socio-hydrological spaces of the Brahmaputra floodplain in Assam, Northeast India: A review. Frontiers in Water. English. 2022;4.
92. Rogers KG, Overeem I. Doomed to drown? Sediment dynamics in the human-controlled floodplains of the active Bengal Delta. Elementa: Science of the Anthropocene. 2017;5.
93. Basak SR, Basak AC, Rahman MA. Impacts of floods on forest trees and their coping strategies in Bangladesh. Weather and Climate Extremes. 2015;7:43-8.
94. Anawar HM, Yoshioka T, Konohira E, Akai J, Freitas M, Tareq SM. Sources of organic carbon and depositional environment in the Bengal delta plain sediments during the Holocene period. Limnology. 2010;11(2): 133-42.
95. Sánez J. Arsenic geochemistry and its impact in public health: The Bangladesh case. Revista de Química. 2008;22(1-2):5-18.
96. Van Soesbergen A, Nilsen K, Burgess ND, Szabo S, Matthews Z. Food and nutrition security trends and challenges in the Ganges Brahmaputra Meghna (GBM) delta. Elementa: Science of the Anthropocene. 2017;5.
97. Jackson RB, Lajtha K, Crow SE, Hugelius G, Kramer MG, Piñeiro G. The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic controls. Annual Review of Ecology, Evolution, and Systematics. 2017;48(1):419-45.
98. Rahman M, Ghosh T, Salehin M, Ghosh A, Haque A, Hossain M. Ganges-Brahmaputra-Meghna Delta, Bangladesh and India: A Transnational Mega-Delta. 2020;23-51.
99. Ranjan A. Water Issues in Himalayan South Asia: Internal Challenges, Disputes and Transboundary Tensions: Springer Nature; 2019.
100. Darms L, Lassois L, Boeraeve F, Hamla S, Sacre P-Y, Derenne A, et al., editors. Restoring the health of walloon agricultural soils by promoting earthworm and microbial activity. 12th International Symposium on Earthworm Ecology; 2022.
101. Mukherjee R, Acharya A, Gupta V, Bakshi S, Paul M, Sanyal P, et al. Diurnal variation of abundance of bacterioplankton and high and low nucleic acid cells in a mangrove dominated estuary of Indian Sundarbans. Continental Shelf Research. 202012/26; 210.
102. Mohanta M, Pradhan BK, Sahu S. Assessment of species diversity and physicochemical characteristics of mangrove vegetation in Odisha, India. 2020;135-51.
103. Smith T, Thomas T, García-Carreras B, Sal S, Yvon-Durocher G, Bell T, et al. Community-level respiration of prokaryotic microbes may rise with global warming. Nature Communications. 201911/12;10:5124.
104. Ghosh A, Dey N, Bera A, Tiwari A, Sathyaniranjan K, Chakrabarti K, et al. Culture independent molecular analysis of bacterial communities in the mangrove sediment of Sundarban, India. Saline Systems. 2010;6(1):1-11.
105. Chattopadhyaya N, Dey BK. Chemoheterotrophic Sulfur Oxidising Microorganisms of a Terai Soil I. Oxidation of Inorganic and Organic Sulfur by Microorganisms, Isolated in Sucrose-Sodiumthiosulfate Agar. Zentralblatt für Mikrobiologie. 1993;148:517-22.
106. Zúñiga-Silgado D, Rivera-Leyva JC, Coleman JJ, Sánchez-Reyez A, Valencia-Díaz S, Serrano M, et al. Soil Type Affects Organic Acid Production and Phosphorus Solubilization Efficiency Mediated by

Several Native Fungal Strains from Mexico. Microorganisms. 2020;8(9). PubMed PMID: 32887277. Pubmed Central PMCID: PMC7565533. Epub 2020/09/06. eng.

107. Halder D, Dutta P, Mondal A, Basu M. Isolation and characterization of halophilic Bacteria from Sundarban Soil. Int J Life Sci Scienti Res. 2016;2(4):442-50.
108. Sengupta A, Chaudhuri S. Vesicular arbuscular mycorrhiza (VAM) in pioneer salt marsh plants of the Ganges river delta in West Bengal (India). Plant and Soil. 1990;122(1):111-3.
109. Behera B, Parida S, Dutta S, Thatoi H. Isolation and identification of cellulose degrading bacteria from mangrove soil of Mahanadi river delta and their cellulase production ability. Am J Microbiol Res. 2014;2(1):41-6.
110. Arifuzzaman M, Khatun M, Rahman H. Isolation and screening of actinomycetes from Sundarbans soil for antibacterial activity. African Journal of Biotechnology. 2010;9(29):4615-9.
111. DE TK. Microbial activity determining soil CO2 emission in the Sundarban mangrove forest, India. Tropical Ecology. 2017;58 (3):525-37.
112. Das S, De M, Ganguly D, Maiti TK, Mukherjee A, Jana TK, et al. Depth integrated microbial community and physico-chemical properties in mangrove soil of Sundarban, India. Advances in Microbiology. 2012;2(03):234.
113. Biswas K, Mukherjee J. Microbial diversity of the Sundarbans, the world's largest tidal mangrove forest, and its bioprospects. Microbial Diversity in Ecosystem Sustainability and Biotechnological Applications: Springer. 2019;231-56.
114. Pramanik A, Sengupta S, Bhattacharyya M. Microbial diversity and community analysis of the Sundarbans mangrove, a world heritage site. Microbial Diversity in the Genomic Era: Elsevier. 2019;65-76.
115. Neogi SB, Dey M, Lutful Kabir S, Masum SJH, Kopprio GA, Yamasaki S, et al. Sundarban mangroves: diversity, ecosystem services and climate change Impacts; 2016.
116. Basak P, Pramanik A, Roy R, Chattopadhyay D, Bhattacharyya M. Cataloguing the bacterial diversity of the Sundarbans mangrove, India in the light of metagenomics. Genomics Data. 2015;4 :90-2.
117. Basak P, Majumder NS, Nag S, Bhattacharyya A, Roy D, Chakraborty A, et al. Spatiotemporal analysis of bacterial diversity in sediments of Sundarbans using parallel 16S rRNA gene tag sequencing. Microbial Ecology. 2015;69(3):500-11.
118. Bhattacharyya A, Majumder NS, Basak P, Mukherji S, Roy D, Nag S, et al. Diversity and distribution of Archaea in the mangrove sediment of Sundarbans. Archaea. 2015;2015.
119. Thatoi H, Behera BC, Mishra RR, Dutta SK. Biodiversity and biotechnological potential of microorganisms from mangrove ecosystems: a review. Annals of Microbiology. 2013 2013/03/01;63(1):1-19.
120. Kumar T, Ghose M. Status of arbuscular mycorrhizal fungi (AMF) in the Sundarbans of India in relation to tidal inundation and chemical properties of soil. Wetlands Ecology and Management. 2008;16(6): 471-83.
121. Pramanik A, Sengupta S, Bhattacharyya M. Chapter 5 - Microbial Diversity and Community Analysis of the Sundarbans Mangrove, a World Heritage Site. In: Das S, Dash HR, editors. Microbial Diversity in the Genomic Era: Academic Press. 2019; 65-76.
122. Isobe KO, Tarao M, Chiem NH, Minh le Y, Takada H. Effect of environmental factors on the relationship between concentrations of coprostanol and fecal indicator bacteria in tropical (Mekong Delta) and temperate (Tokyo) freshwaters. Applied and environmental microbiology. 2004;70(2):814-21.
PubMed PMID: 14766559. Pubmed Central PMCID: PMC348936. Epub 2004/02/10. eng.
123. Phan VTH, Bardelli F, Le Pape P, Couture R-M, Fernandez-Martinez A, Tisserand D, et al. Interplay of S and As in Mekong Delta sediments during redox oscillations. Geoscience Frontiers. 2019/09/01/;10(5):1715-29.
124. Nakhle P, Ribolzi O, Boithias L, Rattanavong S, Auda Y, Sayavong S, et al. Effects of hydrological regime and land use on in-stream Escherichia coli concentration in the Mekong basin, Lao PDR. Scientific Reports. 2021 2021/02/10;11(1):3460.
125. Xuan DT, editor Microbial communities in paddy fields in the Mekong Delta of Vietnam Functional and Molecular Diversity; 2012.

126. Tran Van D. Diversity of the actinomycetes community colonising rice straw residues in cultured soil undergoing various crop rotation systems in the Mekong Delta of Vietnam; 2015.
127. Vu P, Minh V, Vu N, Và T, Thắng T. Soils of the Mekong delta classified by WRB-FAO (2006) classification system. Soil Use and Management. 2013 10/19.
128. Chuenchum P, Xu M, Tang W. Estimation of Soil Erosion and Sediment Yield in the Lancang–Mekong River Using the Modified Revised Universal Soil Loss Equation and GIS Techniques. Water. 2020;12(1):135. PubMed PMID: DOI:10.3390/w12010135
129. Douglas I, Douglas I, Gupta A. The Mekong River Basin. The Physical Geography of Southeast Asia: Oxford University Press. 2005;0.
130. Charles N, Beatrice Njeri O, Loi To Thi B. Anthropogenic Activities as a Source of Stress on Species Diversity in the Mekong River Delta. In: Andrew JM, editor. River Deltas Research. Rijeka: IntechOpen; 2021;9.
131. Dang LV, Ngoc NP, Hung NN. Effects of Biochar, Lime, and Compost Applications on Soil Physicochemical Properties and Yield of Pomelo (Citrus grandis Osbeck) in Alluvial Soil of the Mekong Delta. Applied and Environmental Soil Science. 2022/03/30;202 2:5747 69 9.
132. Egamberdieva D, Wirth S, Bellingrath-Kimura SD, Mishra J, Arora NK. Salt-Tolerant Plant Growth Promoting rhizobacteria for enhancing crop productivity of saline soils. Frontiers in Microbiology. English. 2019;10.
133. Bano N, Nuzhat Khan N, Saleem M, Harrison P, Ahmed S, Azam F. Significance of bacteria in the flux of organic matter in the tidal creeks of the mangrove ecosystem of the Indus River delta, Pakistan. Marine Ecology-progress Series - MAR ECOL-PROGR SER. 1997 10/16;157:1-12.
134. Roland F, Cimbleris A, Lobão L, Vidal L. Bacterioplankton Metabolism in Hydroelectric Reservoirs. Oecologia Australis. 2011 09/01;15:605-17.
135. Khan U, Janjuhah HT, Kontakiotis G, Rehman A, Zarkogiannis SD. Natural Processes and Anthropogenic Activity in the Indus River Sedimentary Environment in Pakistan: A Critical Review. Journal of Marine Science and Engineering. 2021;9 (10):1109. PubMed PMID: doi:10.3390/jmse9101109.
136. Ahmed SI. The marked reduction of the Indus river flow downstream from the Kotry barrage: can the mangrove ecosystems of Pakistan survive in the resulting hypersaline environment? 1992 1992. en.
137. A.A S. Climate Change: Assessing Impact of Seawater Intrusion on Soil, Water and Environment on Indus Delta Using GIS and Remote Sensing Tools Final Report 2018 Principal Investigator; 2019.
138. Farooqui DZ. Mangroves of keti-bunder, indus delta: A present status. Macedonian Journal of Medical Sciences. 2014 05/01.
139. Qamar M. Mangroves of the Active Indus Delta- Changes and their causes. 2009 01/01.
140. Krom M, Shi Z, Stockdale A, Berman-Frank I, Giannakourou A, Herut B, et al. Response of the Eastern Mediterranean Microbial Ecosystem to Dust and Dust Affected by Acid Processing in the Atmosphere. Frontiers in Marine Science. 2016 09/01;3.
141. Sohaib M, Al-Barakah F, Migdadi H, Alyousif M. Isolation and Abundance of Different Culturable Microbes from Mangrove Environments in Coastal Areas of Saudi Arabia. International Journal of Current Microbiology and Applied Sciences. 2022 04/10;11:215-38.
142. P C, R S. Diversity and Distribution of Ciliated Protozoans on the Mangrove Leaf Litters in a Tropical Mangrove Ecosystem; 2021.
143. Abbas N, Nimra, Habib W, Imran I. Monitoring of Mangrove Cover of Western Indus Delta Karachi Pakistan. International Journal of Innovations in Science and Technology. 2021 04/25;3:59-66.
144. Suhail M, Akhund S, Jatt T, Mangrio AM, Abro H, editors. Isolation and identification of penicillium spp., from the river indus bed at Kotri; 2006.
145. Saseeswari A, Kanimozhi G, Panneerselvam A. Bacterial Diversity of Mangrove Soil in Karankadu from East Coast of Tamil Nadu, India. International Journal of Current Microbiology and Applied Sciences. 2016;5:750-6.
146. Babu C, Ramaswamy V, Rao P, Vvss S, Kumar P. A Significant Shift in Particulate Organic Matter Characteristics during Flooding of River Krishna, Eastern

Peninsular India. Current Science. 2020 02/10;118:461.
147. Chintapenta L, Maringanti B, Rath Cc, uln m. Isolation of mangrove fungi from Godavari and Krishna delta of Andhra pradesh, India. Journal of Ecobiology. 2009 01/01;24:91-6.
148. v S, Vittal BPR. Biodiversity of manglicolous fungi on selected plants in the Godavari and Krishna deltas, East coast of India. Fungal Diversity. 2001 02/01;6:115-30.
149. Kumaresan G, Mathavan S. Molecular diversity and phylogenetic analysis of mariner-like transposons in the genome of the silkworm Bombyx mori. Insect molecular biology. 2004;13(3):259-71. PubMed PMID: 15157227. Epub 2004/05/26. eng.
150. Kaushal A, Singh R. Diversity and Seasonal Variation of Soil Fungi Isolated from Surrounding Area of Upper Lake, Bhopal Madhya Pradesh. Advances in Life Science and Technology. 2013;8:1-3.
151. Farooqui A, Bsip R, Nautiyal C. Deltaic land subsidence and sea level fluctuations along the east coast of India since 8 ka: A palynological study. The Holocene. 2016 07/25;26.
152. Behera BC, Yadav H, Singh SK, Mishra RR, Sethi BK, Dutta SK, et al. Phosphate solubilization and acid phosphatase activity of Serratia sp. isolated from mangrove soil of Mahanadi river delta, Odisha, India. Journal of Genetic Engineering and Biotechnology. 2017/06/01/;15(1):169-78.
153. Behera BC, Parida S, Dutta SK, Thatoi HN. Isolation and identification of cellulose degrading bacteria from mangrove soil of Mahanadi River Delta and their cellulase production ability. American Journal of Microbiological Research. 2014/02/09;2 (1):41-6.
154. Doilom M, Guo J-W, Phookamsak R, Mortimer PE, Karunarathna SC, Dong W, et al. Screening of Phosphate-Solubilizing Fungi From Air and Soil in Yunnan, China: Four Novel Species in Aspergillus, Gongronella, Penicillium, and Talaromyces. Frontiers in Microbiology. 2020 2020-October-06;11. English.
155. Thatoi H, Mishra RR, Behera BC. Chapter 20 - Biotechnological potentials of halotolerant and halophilic bacteria from mangrove ecosystems. In: Patra JK, Mishra RR, Thatoi H, editors. Biotechnological utilization of mangrove resources: Academic Press. 2020;413-33.
156. Chen ZL, Xu SY, Xu QX, Hu XF, Yu LZ. Surface water pollution in the Yangtze River Delta: Patterns and countermeasures. Pedosphere. 2002 05/0 1;12:111-20.
157. Lv X, Ma B, Yu J, Chang SX, Xu J, Li Y, et al. Bacterial community structure and function shift along a successional series of tidal flats in the Yellow River Delta. Scientific Reports. 2016/11/08;6(1):36550.
158. Wang H, Liu J, Wang J, Yu W, Xie H-J, Wang S, et al. Different microbial distributions in the Yellow River delta. Desalination and water treatment. 2017 01/01;75:70-8.
159. Wang J, Wang J, Zhang Z, Li Z, Zhang Z, Zhao D, et al. Shifts in the Bacterial Population and Ecosystem Functions in Response to Vegetation in the Yellow River Delta Wetlands. mSystems. 2020;5(3):e00412-20.
160. Shao P, Han H, Sun J, Yang H, Xie H. Salinity Effects on Microbial Derived-C of Coastal Wetland Soils in the Yellow River Delta. Frontiers in Ecology and Evolution. English. 2022;10.
161. Wang S, Dong RM, Dong CZ, Huang L, Jiang H, Wei Y, et al. Diversity of microbial plankton across the Three Gorges Dam of the Yangtze River, China. Geoscience Frontiers. 2012 2012/05/01/;3(3):335-49.
162. Cai W, Li Y, Wang P, Niu L, Zhang W, Wang C. Revealing the relationship between microbial community structure in natural biofilms and the pollution level in urban rivers: a case study in the Qinhuai River basin, Yangtze River Delta. Water science and technology : a journal of the International Association on Water Pollution Research. 2016;74(5):1163-76. PubMed PMID: 27642836. Epub 2016/09/20. eng.
163. Guo X, Li J, Yang F, Yang J, Yin D. Prevalence of sulfonamide and tetracycline resistance genes in drinking water treatment plants in the Yangtze River Delta, China. The Science of the total environment. 2014 Sep 15;493:626-31. PubMed PMID: 24984233. Epub 2014/07/02. eng.
164. Fan L, Song C, Meng S, Qiu L, Zheng Y, Wu W, et al. Spatial distribution of planktonic bacterial and archaeal communities in the upper section of the tidal reach in Yangtze River. Scientific Reports. 2016 2016/12/14;6(1):39147.

165. Zeng X, Liang J, Zeng J, Chen M, Zeng C, Mazur M, et al. Evaluating the effectiveness of three national marine protected areas in the Yangtze River Delta, China. Frontiers in Marine Science. 2022;9. English.
166. Han W-J, Wu D, Zhou J-Z, He Q, Kan Y-J. [Microbial Diversity Analysis of WWTPs Based on Hybrid-MBBR Process in a Low Temperature Season in the Yangtze River Delta]. Huan Jing Ke Xue. 2020 2020/11//;41(11):5037-49.
PubMed PMID: 33124247. chi.
167. Bianchi TS, Butman D, Raymond PA, Ward ND, Kates RJS, Flessa KW, et al. The experimental flow to the Colorado River delta: Effects on carbon mobilization in a dry watercourse. Journal of Geophysical Research: Biogeosciences. 2017;122(3):607-27.
168. Cohn JP. Colorado River Delta. BioScience. 2004;54(5):386-91.
169. Ramond J-B, Jordaan K, Díez B, Heinzelmann SM, Cowan DA. Microbial Biogeochemical Cycling of Nitrogen in Arid Ecosystems. Microbiology and Molecular Biology Reviews. 2022;86(2):e00109-21.
170. Zamora HA, Eastoe CJ, McIntosh JC, Flessa KW. Groundwater Origin and Dynamics on the Eastern Flank of the Colorado River Delta, Mexico. Hydrology. 2021;8(2):80.
PubMed PMID: DOI:10.3390/hydrology8020080
171. Mason O, Canter E, Gillies L, Paisie T, Roberts B. Mississippi River Plume Enriches Microbial Diversity in the Northern Gulf of Mexico. Frontiers in Microbiology. 2016 07/07;7.
172. Saliot A, Cauwet G, Cahet G, Mazaudier D, Daumas R. Microbial activities in the Lena River delta and Laptev Sea. Marine Chemistry. 1996 1996/08/01/;53(3):247-54.
173. Obukhova OV, Lartseva LV. [Halotolerance of enterobacteria isolated from water and fish in the Volga River Delta]. Gigiena i sanitariia. 2015;94(5):28-30.
PubMed PMID: 26625611.
Epub 2015/12/03. rus.
174. Chiţescu CL, Ene A, Geana E-I, Vasile AM, Ciucure CT. Emerging and persistent pollutants in the aquatic ecosystems of the lower danube Basin and North West Black Sea Region—A review. Applied Sciences. 2021;11(20):9721.
PubMed PMID: DOI:10.3390/app11209721
175. Bayoumi H, Patko I. Ecological monitoring of danube water quality in budapest region. American Journal of Environmental Sciences. 2012 01/01;8:202-11.
176. Tohme R, Darwiche N, Gali-Muhtasib H. A Journey Under the Sea: The quest for marine anti-cancer alkaloids. Molecules. 2011;16(11):9665-96.
PubMed PMID: DOI:10.3390/molecules16119665
177. van Soesbergen A, Nilsen K, Burgess ND, Szabo S, Matthews Z. Food and nutrition security trends and challenges in the Ganges Brahmaputra Meghna (GBM) delta. Elementa: Science of the Anthropocene. 2017;5:56.
178. Nakayama T, Tuyet Hoa TT, Harada K, Warisaya M, Asayama M, Hinenoya A, et al. Water metagenomic analysis reveals low bacterial diversity and the presence of antimicrobial residues and resistance genes in a river containing wastewater from backyard aquacultures in the Mekong Delta, Vietnam. Environmental Pollution. 2017 2017/03/01/;222:294-306.
179. Suehiro F, Kobayashi T, Nonaka L, Tuyen BC, Suzuki S. Degradation of Tributyltin in Microcosm Using Mekong River Sediment. Microbial Ecology. 2006;52(1):19-25.
180. Kobayashi T, Suehiro F, Cach Tuyen B, Suzuki S. Distribution and diversity of tetracycline resistance genes encoding ribosomal protection proteins in Mekong river sediments in Vietnam. FEMS Microbiology Ecology. 2007;59(3):729-37.
181. Characterization of three distinct arsenic resistant microorganisms isolated from the agricultural soils of Mekong Delta in Vietnam. 2016. eng.
182. Kosolapov DB. Distribution of Bacteria, Picophytoplankton, and Flagellates in the Mekong Delta. Biology bulletin of the Russian Academy of Sciences. 2022 0000;v.49(no.3): 214-24-2022 v.49 no.3. PubMed PMID: 7794675. English.
183. Nguyen HQ, Huynh TTN, Pathirana A, Van der Steen P. Microbial risk assessment of tidal−induced urban flooding in Can Tho City (Mekong Delta, Vietnam). International Journal of Environmental Research and Public Health. 2017;14(12):1485.
PubMed PMID: DOI:10.3390/ijerph14121485
184. Shah AA, Kasawani I, Jusoff K. Degradation of Indus Delta mangroves in Pakistan. International Journal of Geology. 2007 01/01;3:27-34.

185. Pappas G. Pakistan and water: new pressures on global security and human health. American journal of public health. 2011;101(5):786-8.
PubMed PMID: 21421956. Pubmed Central PMCID: PMC3076420. Epub 2011/03/23. eng.
186. Lee C-W, Bong C-W. Carbon Flux Through Bacteria in a Eutrophic Tropical Environment: Port klang waters. In: Wolanski E, editor. The Environment in Asia Pacific Harbours. Dordrecht: Springer Netherlands. 2006;329-45.
187. Lee SW, Lee CW, Bong CW, Narayanan K, Sim EU-H. The dynamics of attached and free-living bacterial population in tropical coastal waters. Marine and Freshwater Research. 2015;66(8):701-10.
188. Niloufer S, Asst, Sr., Bali L, Engineering R, Mylavaram A, Phirangi S, et al. A study on water quality chanllenges in river krishna due to interlinking of krishna and GODAVARI RIVERS. Waffen-und Kostumkunde. 2021 02/05;11:329-48.
189. Fox BG, Thorn RMS, Anesio AM, Cox T, Attridge JW, Reynolds DM. Microbial Processing and Production of Aquatic Fluorescent Organic Matter in a Model Freshwater System. Water. 2019;11(1):10. PubMed PMID: DOI:10.3390/w11010010.
190. Mondal NC, Saxena V, Singh V. Occurrence of elevated nitrate in ground water of krishna delta, india. African Journal of Environmental science and technology. 2008 01/01:265-71.
191. Ellaiah P, Raju KV, Adinarayana K, Adinarayana G, Saisha V, Madhavi S, et al. Bioactive actinomycetes from Krishna River sediments of Andhra Pradesh. Hindustan antibiotics bulletin. 2002;44(1-4):8-16.
PubMed PMID: 15061588. Epub 2004/04/06. eng.
192. Premke K, Dharanivasan G, Steger K, Nitzsche KN, Jayavignesh V, Nambi IM, et al. Anthropogenic Impact on Tropical Perennial River in South India: Snapshot of Carbon Dynamics and Bacterial Community Composition. Water. 2020;12(5):1354. PubMed PMID: doi:10.3390/w12051354.
193. Higgins SA, Overeem I, Rogers KG, Kalina EA. River linking in India: Downstream impacts on water discharge and suspended sediment transport to deltas. Elementa: Science of the Anthropocene. 2018;6.
194. Radhakrishna I. Saline fresh water interface structure in Mahanadi delta region, Orissa, India. Environmental Geology. 2001 01/17;40:369-80.
195. Mishra M, Patel AK, Behera N, editors. AN Assessment Of Coliform Bacteria In The River Mahanadi System Of Sambalpur; 2012.
196. Mishra M, Patel AK, Behera N, editors. Prevalence of Multidrug Resistant E. Coli in the river Mahanadi of Sambalpur2013.
197. Mishra M, Arukha AP, Patel AK, Behera N, Mohanta TK, Yadav D. Multi-Drug Resistant Coliform: Water Sanitary Standards and Health Hazards. Frontiers in pharmacology. 2018;9:311.
PubMed PMID: 29946253. Pubmed Central PMCID: PMC6005870. Epub 2018/06/28. eng.
198. Nanda SN, Tiwari TN. Effect of discharge of municipal sewage on the quality of river Mahanadi at Sambalpur. Indian Journal of Environmental Protection. 2001 04/01;21:336-43.
199. Behera BC, Patra M, Dutta SK, Thatoi HN. Isolation and Characterisation of Sulphur Oxidising Bacteria from Mangrove Soil of Mahanadi River Delta and Their Sulphur Oxidising Ability. Journal of Applied & Environmental Microbiology. 2014 2013/12/28;2(1):1-5.
200. Behera BC, Mishra RR, Singh SK, Dutta SK, Thatoi H. Cellulase from Bacillus licheniformis and Brucella sp. isolated from mangrove soils of Mahanadi river delta, Odisha, India. Biocatalysis and Biotransformation. 2016 2016/01/02;34(1):44-53.
201. Behera BC, Patra MM, Dutta SK, Thatoi H, editors. Isolation and Characterisation of Sulphur Oxidising Bacteria from Mangrove Soil of Mahanadi River Delta and Their Sulphur Oxidising Ability; 2014.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/114071