# Scientometric Analysis of Ecotoxicological Investigations of Xenobiotics in Aquatic Animals

**Bejawada Chanikya Naidu, M. D. Sahana, Muzammal Hoque, and S. Abuthagir Iburahim**

## 1 Introduction

### *1.1 What Are Xenobiotics?*

A chemical substance that is not created naturally by the organism or that was not anticipated to be there is referred to as a xenobiotic (Malchi et al. 2022). They are present in significantly higher concentrations than typical and are frequently discussed in relation to environmental pollutants like polychlorinated biphenyls and dioxins and how they affect the biota (Gupta et al. 2022). They exist in both organic and inorganic forms and can mimic substances produced biologically that are necessary for life. Usually chemicals that are foreign to animal life are referred to as ‘xenobiotics’, and examples of these include plant elements, medications, insecticides, cosmetics, flavourings, scents, food additives, industrial chemicals, and environmental contaminants (Štefanac et al. 2021). Xenobiotics are of two types: exogenous and endogenous. Exogenous xenobiotics are those that enter an organism through food, medication, or environmental inhalation but are not generally created by the organism itself (e.g. chemicals, pharmaceuticals, pollutants, pesticides, and food additives). Endogenous xenobiotics are physiologically produced substances that resemble exogenous xenobiotic chemicals in some ways (Brandts et al. 2021). These are either created by the human body during various activities or are formed as metabolites (e.g. Eicosanoids, specific fatty acids, bile acids, bilirubin, and steroids). These compounds have the potential to be problematic, and it is important to investigate both their immediate and long-term impacts on people, animals, and the environment (Ortiz et al. 2022). These are either nonbiodegradable or only

B. Chanikya Naidu (✉) · M. D. Sahana · M. Hoque · S. Abuthagir Iburahim
ICAR-Central Institute of Fisheries Education, Mumbai, India
e-mail: chanikya.frmpb006@cife.edu.in

 
M. A. Rather et al. (eds.), *Xenobiotics in Aquatic Animals*,
https://doi.org/10.1007/978-981-99-1214-8_15

partially biodegradable, have a slow rate of biotransformation, and can last a very long time in the environment (Bhatt et al. 2021).

## 1.2 Xenobiotics in Various Fields

Since many chemical and pharmaceutical businesses use xenobiotics to make medicines, plastics, detergents, gels, research laboratory chemicals and biochemical kits, perfumes, herbicides, insecticides, and a wide range of other items, xenobiotics are essential for people and society. Many compounds used to enhance daily life (antibiotics, pesticides, dyes, PCPs, additives, etc.) have been developed as a result of technological advancement in the twentieth century; these compounds may not always occur naturally in the environment or may do so at concentrations that are significantly different from those brought on by anthropogenic activity (Mishra et al. 2019). They are categorised as pesticides, pharmaceutical chemicals, personal care items, illegal substances, industrial goods, and nuclear waste and can be found in the air, soil, water, plants, animals, and people (Malchi et al. 2022). Industries, including paper and pulp, fossil fuels, pesticides, explosives, and pharmaceuticals, among others, are important contributors of xenobiotic chemicals to the environment (Faggio et al. 2018).

## 1.3 World Scenario of Xenobiotics

In their lifetimes, humans are thought to be exposed to one to three million xenobiotics (Esteves et al. 2021). Most of these chemicals undergo a variety of detoxication processes that, in general, make them less poisonous, more polar, and easily excretable before entering the body through nutrition, air, drinking water, drug administration, and lifestyle choices (Collins and Patterson 2020). Xenobiotic pollution of the environment and, consequently, the uptake of these substances by living things have both increased dramatically in recent decades. The introduction of these compounds to ecosystems may result in an increase in allergic reactions, increased mortality of organisms, genetic changes, lowered immune systems, metabolic problems, and disturbances of ecosystem processes all the way up to the biosphere (Kucherenko et al. 2021). There are several immediate and long-term repercussions on natural ecosystems as a result of the diverse medications used, which have caused the release of dangerous chemicals into aquatic areas. Ecosystems are directly impacted by xenobiotics, changing things like community parameters, community structure, diversity, productivity, and energy transfer, as well as succession and population density (Wang et al. 2022). The world develops up to one million new products a year, including about 100,000 chemical compounds. Nearly 15,000 of these are considered possible xenobiotics. Particularly dangerous is the pesticide, hormone, and trans-fatty acid contamination of food (Gan et al. 2022).

### 1.4 Xenobiotics in Aquatic Environments

In typical sewage treatment facilities, some xenobiotic chemicals are nonbiodegradable and discharged with treated runoff, which could contaminate aquatic systems like rivers, lakes, and estuaries. Common xenobiotic receptors exist in traditional sewage treatment plants and must be treated with municipal wastewater before being released into aquatic systems (Maculewicz et al. 2020). Some trace metals, xenobiotic substances, and synthetic organic chemicals, such as PAHs, phthalates, and pesticides, can be detected in water bodies (Dar et al. 2020; Štefanac et al. 2021). Xenobiotic substances that are released into surface water may leak into groundwater, although this practice is currently severely prohibited since it could compromise the ecological integrity of aquatic ecosystems (Tonelli and Tonelli 2020).

### 1.5 How It Affects the Aquatic Environment

Within aquatic ecosystems any exposure to xenobiotics in sediment may have negative impacts at lower trophic levels and/or biomagnify and have more severe negative toxic effects at higher trophic levels (Tonelli and Tonelli 2020). Over the past century, there has been a tremendous growth in the variety of synthetic, xenobiotic compounds entering the environment. Their ecological effects in aquatic ecosystems are still poorly known in terms of their nature and severity (Arya and Haq 2019). Long after their original release into the aquatic environment, these hazardous, bioaccumulative, and persistent chemicals still run the danger of having deleterious impacts at all levels of biological organisation. Aquatic species experience oxidative stress and endocrine disruption as a result of the presence of xenobiotic contaminants (Mohapatra et al. 2021; Curpan et al. 2022). Their influence on aquatic ecosystems is well documented, and the manner in which they affect fish and other aquatic creatures can be broadly divided into three categories: behavioural, neurophysiological, and reproductive (Chandana and Kote 2020). It is a global concern that xenobiotic substances, such as poly aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), polychlorinated biphenyls (PCBs), organochlorine pesticides (OC), heavy metals, tri-butyl tin (TBT), etc., are contaminating the marine environment through various pathways (Gupta et al. 2022). A significant threat to the health of the marine ecosystem is posed by the bioaccumulation of their residues into the tissues of marine creature by considering the importance of the topic we have performed a meta-analysis on xenobiotics to know the trend of research in xenobiotics which will assist the present and future researchers in the particular field.

## 2 Materials and Methods

In order to guide future research by evaluating knowledge domains, measurable research patterns and intellectual structure, social structures, and emergent research themes, we performed a scientometric study of xenobiotics-related research in this work. The visualisation of data through scientometric analysis allows researchers to examine major changes and developments in the field of study, as well as its overall expansion. In addition, scientometric analysis can spot trends, collaborations, and patterns in publications on a certain subject or field of study. In this paper, the research on xenobiotics was quantitatively displayed and reviewed in a systematic fashion using scientometric techniques. The research made use of the Web of Science (WoS) database (Clarivate Analytics, Philadelphia, Pennsylvania), which includes articles from more than 21,100 high-quality scholarly journals from around the world, covering more than 250 different fields of study (https://clarivate.com/webofsciencegroup/solutions/web-of-science-corecollection/). Microsoft Excel 2019, Vos Viewer and R-studio were used to export the bibliometrics records from the WoS database and conduct the analysis. Average citations per article (ACPP), h-index, and total citations were used to determine how productive institutions and authors were. The h-index is a metric used to evaluate a researcher's productivity in the scientific community by analysing the correlation between their number of citations and the impact of their most highly referenced works (Hirsch 2005). To make bibliometric network maps that anyone can understand, R-studio is utilised. The software package R-studio was utilised to illustrate the hierarchy of command, conduct a co-authorship study, and visualise the citation relationships between individual writers and their respective publications. Different hues were assigned to different clusters (Waltman et al. 2010). The bibliometrics R-package in R version 4.0.1 and R-studio version 1.3.959 was used to examine the retrieved metadata from WoS. Biblioshiny was used for numerous analyses in this scientometrics report, including trend topics, thematic progression, and multiple country publication. Associations between nations, authors, and keywords were used to partition the dataset into multiple color-coded clusters (Van Eck et al. 2010; Waltman et al. 2010). The network visualisation technique was used to depict the connections between them all, with the proximity of two circles representing how closely they are related (Khalil and Crawford 2015; Zhao et al. 2018).

## 3 Results and Discussion

### *3.1 Xenobiotics*

Scientometric studies examine the development of science in a field that may show the importance of a study, author, or research facility. In the particular subject of science, it is used to compare the influence of a research paper, researcher, journal,

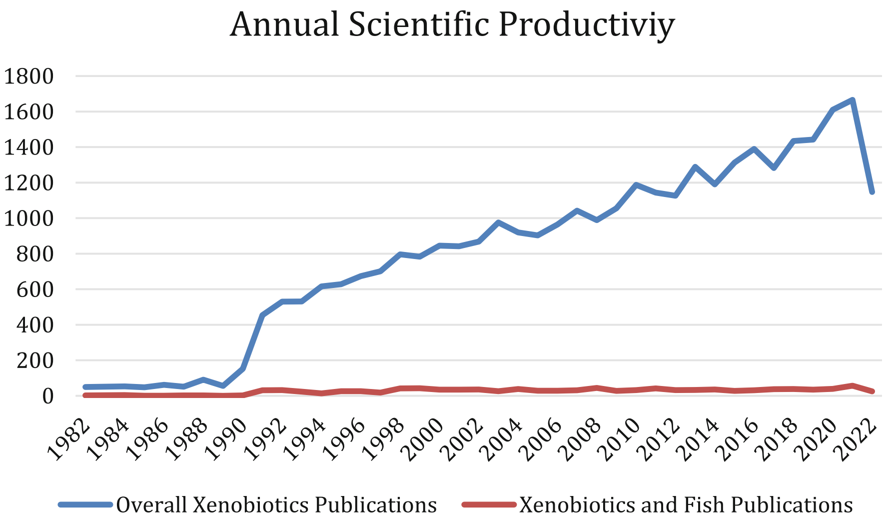


**Fig. 1** Annual scientific production trend of research on xenobiotics and xenobiotics in fish

and institutions. Based on a search of the WoS database from 1982 to 2022 using the keywords 'xenobiotics', 'xenobiotics in fish', and 'impact of xenobiotics on fish physiology', this study was conducted to assess the amount of scholarly material on xenobiotics that was available. Between 1982 and 2022, journals included in the xenobiotics WoS category published a total of 33,056 documents on xenobiotics. In 1955, there was the first instance of a scientific paper on xenobiotics that was indexed in the WoS. The metabolism of xenobiotics and other medications was covered in the first publication (Testa 1955). There was a sharp rise in research publications on xenobiotics in the year 1988 and the trend followed till 2020 (Fig. 1). With an average of two authors per document (1.61%), 0.629 documents per author, and a collaboration index of 1.68, there were about 52,574 authors. The average number of citations per document was 37.84, indicating that the documents were of significant academic and research value.

The results of the scientometric analysis show that, between 1982 and 2022, the United States contributed the most publications (30.38%), followed by Germany, China, Japan, and France (Fig. 2).

Pharmacology, toxicology, molecular biology, and ecology were the main areas of concentration for xenobiotics-focused research and scientific publications that took place throughout the past 40 years in many different fields (Fig. 3). Pharmacology leads the field of xenobiotics research with 4070 articles, followed by toxicology (3564), molecular biology (3131), and ecology (2570). Significant xenobiotic research was conducted alongside work in cell biology, biotechnology, genetics, and engineering.

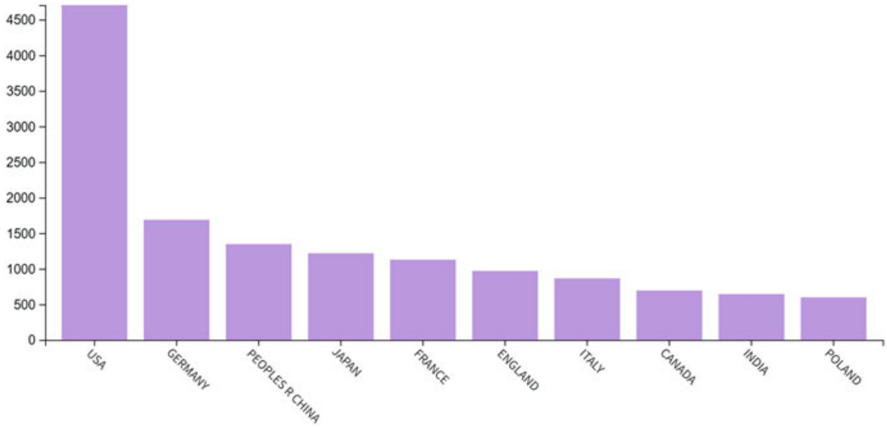


**Fig. 2** Publication output of top 10 countries on xenobiotics research

### *3.2 Xenobiotics in Fish*

With an average citation per document of 35.71 and a collaboration index of 3.79, about 3876 writers have contributed to 1080 documents about xenobiotics in fish study. According to scientometric study, the top contributing nations for xenobiotics in fish research were the developed nations like the United States, France, Germany, Canada, and China (Fig. 4).

The study of xenobiotics in fish initially fluctuated greatly year to year and peaked in the previous decade. The main institutions that contributed to the research were Oregon State University, the Rudjer Boskovic Institute, the USEPA, the Chinese Academy of Sciences, the University of Aveiro, and the Spanish National Research Council (CSIC). The top researchers in the field of xenobiotics in fish include Andersson, Goksoyr, Schlenk, Cashman, Forlin, James, Pritchard, Monod, and Buhler with a great rate of collaboration (Fig. 5).

### *3.3 Effect of Xenobiotics on Fish Physiology*

The effect of xenobiotics on fish physiology was the subject of scientometric analysis, which found a total of 65 published documents by 253 contributing authors, with a collaboration index of 4.13 and an average number of citations per document of 50.71. The publications did not follow any trend over the years with comparatively higher number of publications in 2017 (Fig. 6).

Most research on xenobiotics effects on fish physiology has been done in the domains of toxicology, marine freshwater ecology, endocrine metabolism, and fish pharmacology. Sugiyama, Yamazaki, Gershwin, and Wang are among the authors


**Fig. 3** Major focus areas in xenobiotics and its related research during 1982–2022


**Fig. 4** Major countries contributing to xenobiotics in fish research during 1982–2022

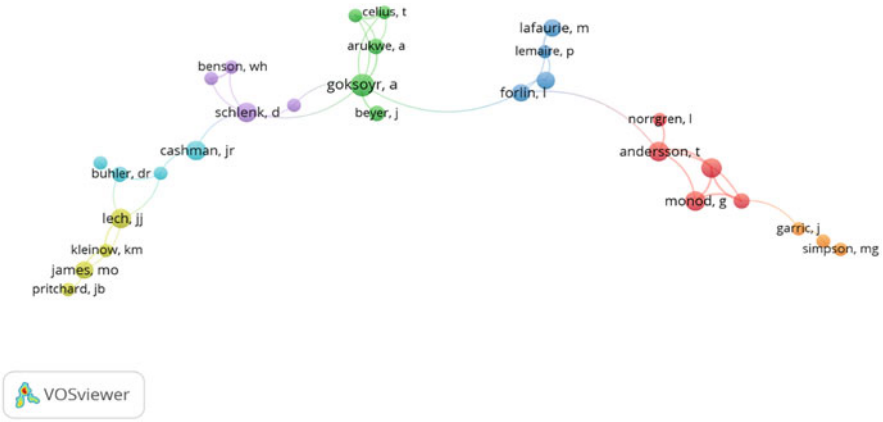


**Fig. 5** Top researchers in the field of xenobiotics in fish from various countries

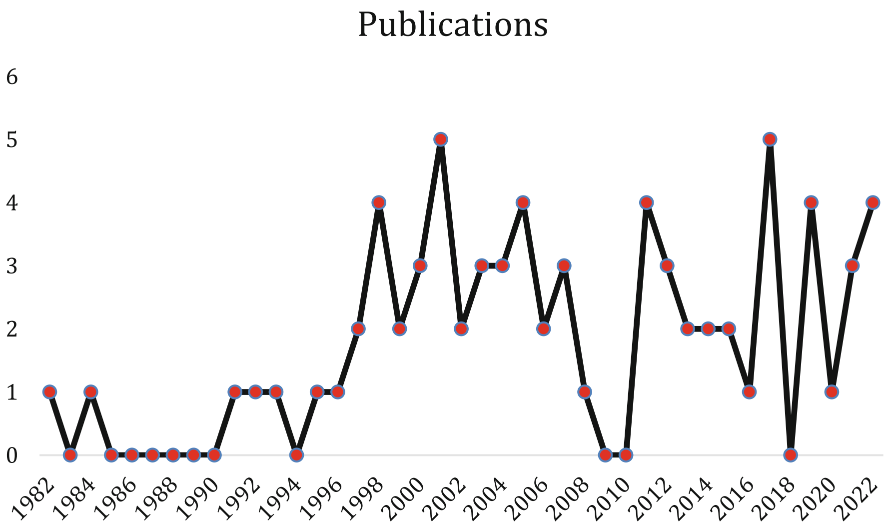


**Fig. 6** Annual scientific production trend of research on the effect of xenobiotics on fish physiology during 1982–2022

who have contributed the most to studies on xenobiotics effects on fish physiology, and the most influential countries in the research on xenobiotics effects on fish physiology were the United States, Japan, China, and the United Kingdom (Fig. 7).

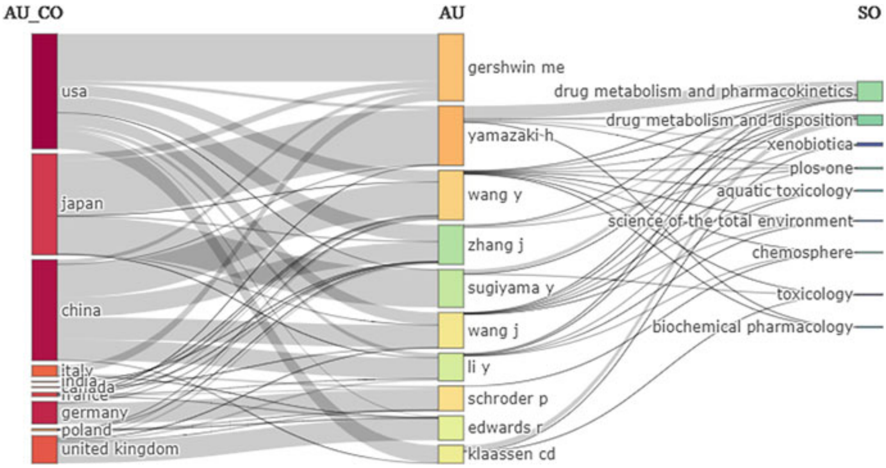


**Fig. 7** Highly productive authors of research on the effect of xenobiotics on fish physiology, their networking, and the research source

## 4 Conclusion

The United States, Germany, and China had more publications in the current study than the other nations combined. China and the United States are large producers of xenobiotics, and perhaps as a result of the negative effects that these xenobiotics have had on their aquatic ecosystems and environment, more study has been conducted in these nations. To have a broad overview of the research investigations conducted in this research field, 33,056 research publications in total were analysed. The research literature produced between 1982 and 2022 was divided and assessed to determine the change in the pattern of authorship and their affiliation. It highlighted the key regions, nations, and authors who are leading the field of research on xenobiotics in fish. In this study, a moderately high level of collaboration was identified both between and within nations. Additionally, it was discovered that developed countries with advanced scientific and technological infrastructure had begun xenobiotics-based research much earlier and produced a large number of publications. However, very recently, the trend has changed as developing countries like India have taken on the difficult studies of xenobiotics in aquatic environments and their effects. The study's scope was constrained by the fact that it was nearly entirely dependent on datasets obtained through WoS. However, the study's general patterns and important measures may be used as a basis for deciding how to strengthen institutions, collaborate more effectively, increase grants, and prioritise research priorities. Similar scientometric analyses of numerous xenobiotics effect on diverse aquatic creatures over time could undoubtedly aid in understanding the direction of the field's study. The scientometrics analysis that was undertaken gives a global picture of research on xenobiotics in developed as well as emerging nations. Policymakers will find the data helpful in identifying the dominant trends in this area. Governments can use it to plan for the future, spending money on new research. Additionally, it has emphasised the key institutions for financial advice and networking, academics for spotting hot-button research subject with the influential and active individuals in the sector, and industries to discover solutions to the xenobiotics in aquatic environment issues. As a result, this research report will aid in identifying potential future line of works.

## 5 Virtual Reality Application in Various Domains

| S. no | Domain | Application | Source |
|---|---|---|---|
| 1 | Agriculture | VR-based simulation of the natural environment for cows to improve quantity and quality of milk | https://www.agritechtomorrow.com/article/2020/11/smart-farming-is-ready-for-augmented-and-virtual-reality/12516 |
| 2 | Medicinal science | Application of VR to understand the complex treatment procedure before carrying out the treatment to the patients | https://www.news-medical.net/health/Applications-of-Virtual-Reality-in-Medicine.aspx |
| 3 | Remote sensing and GIS | VR- based interaction with real objects using 3D visualisation | Singla (2021) |
| 4 | Oceanography | VR- based creation of plankton zoo and 3D visualisation of plankton to learn about phytoplankton | Walcutt et al. (2019) |
| 5 | Oceanography | VR application in mimicking natural habitat to elicit behavioural response (e.g. camouflage) in *Loligo opalescens* | Jaffe et al. (2011), Josef (2018) |
| 6 | Oceanography | Creation of immersive virtual aquarium with real-walking navigation by using VR | Jung et al. (2013) |
| 7 | Fishing areas | Application of VR to map the fishing location present in the US country to know about the different fishing locations | https://www.gmw3.com/2021/12/go-us-west-coast-fishing-in-real-vr-fishings-upcoming-dlc/ |
| 8 | Engineering and design | VR- based creation of prototype machinery to examineand modify any defects in the system rather than making a physical prototype | https://www.xcubelabs.com/blog/the-applications-of-virtual-reality-in-the-manufacturing-industry/ |
| 9 | Military | Application of VR for realistic military training to combat high-stress situations and improve skills over handling weapons and range of communications. | https://www.futurevisual.com/blog/uses-vr-military-training/ |

(continued)

| S. no | Domain | Application | Source |
|---|---|---|---|
| 10 | Sports | VR sports entertainment accelerates the athletes training regimen, giving them a chance to run unlimited reps to perform better in a true event | https://www.strivr.com/solutions/industries/sports/#:~:text=A%20Virtual%20Reality%20(VR)%20sports,best%20when%20it%20truly%20matters |
| 11 | Manufacturing | VR- based manufacturing will allow the worker to interact with the inside of an engine to create, repair and to maintain the machinery | https://www.onewatt.eu/post/extended-reality-in-machine-maintenance-and-repair |
| 12 | Veterinary medicine | Application of VR to understand the anatomy of dog, cow, and equine | https://guides.lib.vt.edu/vetmed/vranatomy |
| 13 | Tourism | VR technology implementation of smart tourism to provide information about destinations and attractions while showing its potential to become a new tourism service | Pestek and Sarvan (2020) |
| 14 | Entertainment | VR- based games, theatre, museum, amusement park, gallery, live music concerts, hobby lessons | https://jasoren.com/virtual-reality-for-the-entertainment/ |
| 15 | Archaeology | A prototype of Pleito Cave was reconstructed by using VR which leads to understanding the real-time information of the caves | Cassidy et al. (2019) |
| 16 | Education | VR- based learning is a promising tool to learn the concepts clearly and also engages multiple senses | Christou (2010) |
| 17 | Forestry | Application of VR to map the presence of jaguars throughout the Peruvian Amazon for the effective conservation | Bednarz et al. (2016) |
| 18 | Environment | Application of VR to know the individual carbon print in their daily activities will make them think in a different way to reduce carbon footprints | https://www.unep.org/news-and-stories/story/experience-your-carbon-footprint-vr |
| 19 | Horticulture | VR- based learning of plant physiology can make the individual to grow the plant and can make them to tackle the arising problem effectively | Ai-guo et al. (2011) |
| 20 | Medicine | VR technology employed in the drug discovery by engaging different scientist in a place for real-time modification or identification of molecules or drugs | https://www.labcompare.com/10-Featured-Articles/577506-VR-for-Science-Drug-Discovery-and-More-in-the-Virtual-World/ |

## 6 Status of Fisheries Education in India

In comparison to veterinary and agricultural education, professional fisheries education in India got established later. The Central Institute of Fisheries Education in Mumbai was started in 1961, and it was in 1969, under the auspices of the University of Agricultural Sciences, Bengaluru, that the first Fisheries College in Mangalore opened, marking a new era in the professional fisheries education in India at the State Agricultural/Veterinary Universities. There are more than 32 fisheries colleges and 3 universities offering fisheries education in India for bachelors, and master and PhD degree programmes. The present annual intake capacity of the B.F.Sc., M.F.Sc., and PhD programme is 1500, 425, and 185, respectively, while the annual out turn is about 80–85% of intake (Kumar et al. 2018). Universities and colleges have always been at the forefront of new technologies, driving innovation, changing industries, and training the next generation of scientists, developers, and business owners. Right now, virtual and augmented reality technologies are at the cutting edge of progress, and things are changing quickly.

## 7 Possible Virtual Reality Application in Fisheries Education

Immersive VR application allows the students to reach to any possible environment without being actually present.

## 8 Distance Learning/Virtual Classrooms

Students who are able to think creatively have a better shot at learning the problem-solving, teamwork, and efficiency skills they will need in college and beyond. Teachers can employ exploration-based learning, an active learning strategy that encourages students to learn through curiosity and enquiry, to assist students to acquire confidence and make their education more meaningful (Fig. 8). The concept of distance learning is growing up after the Covid-19 lockdown as people get used to online learning platforms. One of the major problems in online learning platforms is physical engagement, which can be sorted out by virtual reality. Virtual reality classroom in many examples showed significantly better learning motivation, learning outcomes, and positive impacts on learning students' achievement scores (Liou and Chang 2018).


**Fig. 8** Virtual reality benefits in education

## 9 Virtual Field Visits

Visiting a real workplace, especially one that could put students in harm's way, can be prohibitively expensive and time-consuming for those pursuing a practical education. The simulations on underwater environment like trench, coral reef areas; real-time fishing in ocean and freshwater environments, research cruise, aquaculture farms, virtual museums, climate change studies, etc., can be created, which can enable the student to visit these areas from their convenient places and cut down the travelling cost and time. VR creates psychological presence, a sense of being there, due to the immersive VR tracking system that detects the user's body movements and enables them to feel as though their body is moving in the virtual world and the virtual world is reacting to their movement. VR is an effective treatment for some of the phobias like aquaphobia (Morina et al. 2015) and anxiety disorder (Opriş et al. 2012) due to its high level of presence. Virtual reality meetings such as conferences, workshops, and symposia are gaining popularity all over the world. One of the best examples in the fisheries is the thirteenth AFAF (Asian fisheries aquaculture forum) held in virtual mode in 2022.

## 10 Virtual Fish and Fish Systems

Traditionally, textbooks, live animals, and cadavers are used in fisheries anatomy and biology classes to develop a solid foundation of knowledge. The practical connectivity of students in the anatomy of finfish and shellfish, and biology of finfish and shellfish systems is difficult in the textbook education. Three-dimensional (3D) software programs provide a platform for deeper examination of anatomical structures but are unable to deliver a fully immersive experience. The use of virtual reality (VR) provides a new type of learning environment and avoid sacrificing live organisms (Fig. 9). Dissection and identification of vital organs by the students themselves will be very easy in the VR environment as the users can zoom in and zoom out the parts and they can know the functions of the organs and systems.

## 11 Virtual Labs

As the accreditation criteria of many accrediting bodies emphasise, acquiring practical skills is a critical component of learning outcomes in any fisheries degree. It will be especially difficult to ensure efficient achievement of these skills with limited physical delivery. One possible solution to this problem is to use virtual lab experiments and simulations to help students understand the concepts, important relationships between variables, and potential impact on experimental rig operation before physically carrying out an experiment in a laboratory within a much shorter

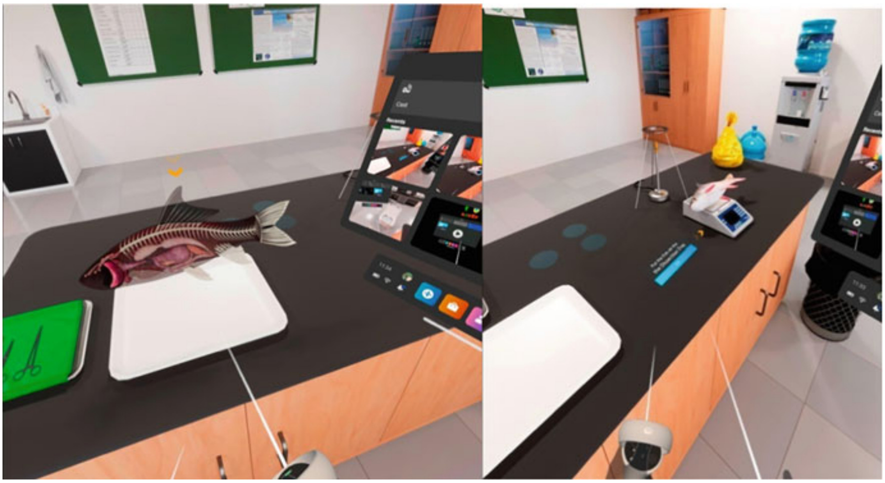

**Fig. 9** Glimpse of the Virtual Fish Laboratory developed under NAHEP

**Fig. 10** Students of ICAR-CIFE enjoying the virtual reality programme

timeline. Field of cell biology, toxicology, pharmacology, histology, and pathology studies in aquatic organisms involves hazardous or toxic chemicals in laboratories, which can be avoided in VR education. The wastage of costly chemicals also can be overcome in VR education, and the experiment for teaching can be repeated n number of times (Fig. 10).

## 12 Conclusion

Those interested in the new teaching technique should not miss this chance to learn more. Virtual reality has the potential to completely transform education at all levels by bringing a new dimension to the learning process. Augmented reality promotes student learning and comprehension through experimentation. We are currently only witnessing the beginnings of a paradigm shift in education brought about by virtual technologies. Increasing accessibility is another key component of the future of VR in the classroom. It benefits both education and technology. Augmented reality is gaining popularity as application development incorporates new technology. As VR hardware and software continue to decrease in price, it will soon permeate all facets of the educational system. Virtual reality (VR) solutions have been proven effective across a variety of educational settings, and they are generally well received by viewers. Augmented reality (AR) can transform human existence due to its many benefits. We must assess unsolved research problems about virtual reality's (VR) future barriers and potential benefits. Recent advances in telecommunication systems, especially the rollout of the 5G network in big economies like China, India, and the United States, will boost VR-based markets. The Web 3.0 is the next big revolution that is happening in the world today. The ongoing Covid-19 pandemic pushed the world to adapt and evolve to challenging situations to keep the economy running. Every aspect of life, be it education, shopping, running business, banking, and attending office, became online. Being online is the new normal these days. This is why VR is going to have a huge impact in all the sectors. VR is increasingly used in education and training in academia, healthcare, tourism, shopping, and in automobile and space industries. From an educational point of view, VR will revolutionise the learning experience. Students can immerse and understand subjects that are challenging to grasp via conventional learning. Increase in educational content in the VR arena will certainly take education to the next level in the coming generations. Medical students can have real-time experience in complex surgeries via pre-recorded real-time surgery videos captured directly through the eyes of the surgeon himself and an engineering student can have hands-on training in 3D modelling of complex machineries. A fishery student in relative terms will get to experience real-time immersive knowledge in a variety of aspects like underwater oceanic observations, craft and gear handling at the sea, fish processing in big industries, aqua feed production in feed manufacturing plants, and hatchery operations to which the students have limited accessibility in many grad schools. In limited resource settings, VR contents can be crafted to aid the students' needs. For example, it is not always necessary for all students to dissect a fish to learn different parts of its body; every time the student will not get exposure to study taxonomy of diverse fish groups within a semester, as fish availability depends on the season and fishing effort which varies substantially across the country. VR can solve these problems by creating interactive contents to give students a real-time immersive learning experience around the year and across the country. Not only does this adaptation make learning wholesome, it cuts down costs and resources associated with it.

## References

Ai-guo Z, Ping S, He G (2011) The technology of VR and its application in the experimental teaching of plant physiology. In: 2011 International Conference on E-Business and E-Government (ICEE). IEEE, pp 1–2

Applications of Virtual Reality in Medicine, https://www.news-medical.net/health/Applications-of-Virtual-Reality-in-Medicine.aspx

Arya P, Haq SA (2019) Effects of xenobiotics and their biodegradation in marine life. In: Smart bioremediation technologies. Academic Press, pp 63–81

Augmented Reality and Virtual Reality (AR & VR) Market size is expected to reach USD 571.42 Billion by 2025. Valuates Reports

Bednarz T, Kim J, Brown R, James A, Burrage K, Clifford S, Davis J, Mengersen K, Peterson E, Psaltis S, Vercelloni J (2016) Virtual reality for conservation. In: Proceedings of the 21st international conference on web3d technology, pp 177–178

Bhatt P, Bhandari G, Bhatt K, Maithani D, Mishra S, Gangola S, Bhatt R, Huang Y, Chen S (2021) Plasmid-mediated catabolism for the removal of xenobiotics from the environment. J Hazard Mater 420:126618

Blascovich J, Loomis J, Beall AC, Swinth KR, Hoyt CL, Bailenson JN (2002) Immersive virtual environment technology as a methodological tool for social psychology. Psychol Inq 13(2): 103–124

Bowman DA, McMahan RP (2007) Virtual reality: how much immersion is enough? Computer 40(7):36–43

Brandts I, Solà R, Martins MA, Tvarijonaviciute A, Barreto A, Teles M, Oliveira M (2021) A baseline study on the impact of nanoplastics on the portals of entry of xenobiotics in fish. Mar Pollut Bull 173:113018

Cassidy B, Sim G, Robinson DW, Gandy D (2019) A virtual reality platform for analyzing remote archaeological sites. Interact Comput 31(2):167–176

Chandana GL, Kote NV, Sharath Chandra SP (2020) Recent scenario of impact of xenobiotics on marine fish: an overview. Pharm J 12(6s):1797–1800

Christou C (2010) Virtual reality in education. In: Affective, interactive and cognitive methods for e-learning design: creating an optimal education experience. IGI Global, pp 228–243

Collins SL, Patterson AD (2020) The gut microbiome: an orchestrator of xenobiotic metabolism. Acta Pharm Sin B 10(1):19–32

Cuesta Cambra U, Manas Viniegra L (2016) Integration of immersive virtual reality in communication degrees. Revista Icono 14-Revista Cientifica De Comunicacion Y Tecnologias 14(2)

Curpan AS, Impellitteri F, Plavan G, Ciobica A, Faggio C (2022) Mytilus galloprovincialis: an essential, low-cost model organism for the impact of xenobiotics on oxidative stress and public health. Comp Biochem Physiol C Toxicol Pharmacol 256:109302

Dar SA, Chatterjee A, Rather MA, Chetia D, Srivastava PP, Gupta S (2020) Identification, functional characterization and expression profiling of cytochrome p450 1A (CYP1A) gene in *Labeo rohita* against emamectin benzoate. Int J Biol Macromol 158:1268–1278

Di Natale AF, Repetto C, Riva G, Villani D (2020) Immersive virtual reality in K-12 and higher education: a 10-year systematic review of empirical research. Br J Educ Technol 51(6): 2006–2033

Esteves F, Rueff J, Kranendonk M (2021) The central role of cytochrome P450 in xenobiotic metabolism—a brief review on a fascinating enzyme family. J Xenobiot 11(3):94–114

Experience your carbon footprint in VR, https://www.unep.org/news-and-stories/story/experience-your-carbon-footprint-vr

Extended Reality in Machine Maintenance and Repair, https://www.onewatt.eu/post/extended-reality-in-machine-maintenance-and-repair

Faggio C, Tsarpali V, Dailianis S (2018) Mussel digestive gland as a model tissue for assessing xenobiotics: an overview. Sci Total Environ 636:220–229

Freina L, Ott M (2015) A literature review on immersive virtual reality in education: state of the art and perspectives. In: The international scientific conference elearning and software for education, vol 1, no 133, pp 10–1007

Gan J, Ashraf SS, Bilal M, Iqbal HM (2022) Biodegradation of environmental pollutants using catalase-based biocatalytic systems. Environ Res 214(Pt 2):113914

Gavish N, Gutiérrez T, Webel S, Rodríguez J, Peveri M, Bockholt U, Tecchia F (2015) Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. Interact Learn Environ 23(6):778–798

Global AR and VR Market to Reach USD 165.3 billion by 2027. https://www.vynzresearch.com/ict-media/augmented-reality-and-virtual-reality-market

Go US West Coast Fishing in Real VR Fishing's Upcoming DLC – VRFocus, https://kalem.easterndns.com/news/2021/12/01/go-us-west-coast-fishing-in-real-vr-fishings-upcoming-dlc-vrfocus/

Gupta SK, Singh B, Mungray AK, Bharti R, Nema AK, Pant KK, Mulla SI (2022) Bioelectrochemical technologies for removal of xenobiotics from wastewater. Sustain Energ Technol Assessm 49:101652

Harrington CM, Kavanagh DO, Quinlan JF, Ryan D, Dicker P, O'Keeffe D, Tierney S (2018) Development and evaluation of a trauma decision-making simulator in Oculus virtual reality. Am J Surg 215(1):42–47

Hirsch JE (2005) An index to quantify an individual's scientific research output. Proc Natl Acad Sci 102(46):16569–16572

Ibañez-Etxeberria A, Gómez-Carrasco CJ, Fontal O, García-Ceballos S (2020) Virtual environments and augmented reality applied to heritage education. An evaluative study. Appl Sci 10(7): 2352

Jaffe JS, Laxton B, Zylinski S (2011) The Sub Sea holodeck: a 14-megapixel immersive virtual environment for studying cephalopod camouflage behavior. In: OCEANS 2011 IEEE-Spain. IEEE, pp 1–6

Jensen L, Konradsen F (2018) A review of the use of virtual reality head-mounted displays in education and training. Educ Inf Technol 23(4):1515–1529

Josef N (2018) Cephalopod experimental projected habitat (CEPH): virtual reality for underwater organisms. Front Mar Sci 5:73

Jung S, Choi YS, Choi JS, Koo BK, Lee WH (2013) Immersive virtual aquarium with real-walking navigation. In: Proceedings of the 12th ACM SIGGRAPH international conference on virtual-reality continuum and its applications in industry, pp 291–294

Kalyvioti K, Mikropoulos TA (2014) Virtual environments and dyslexia: a literature review. Proc Comp Sci 27:138–147

Khalil GM, Crawford CAG (2015) A bibliometric analysis of US-based research on the behavioral risk factor surveillance system. Am J Prev Med 48(1):50–57

Kucherenko SV, Ovcharenko AM, Pushenko SL (2021) Xenobiotics: a threat to the health of living organisms. In: E3S web of conferences, vol 285. EDP Sciences, p 03006

Kumar M, Gurjar UR, Keer NR, Kumar S (2018) Professional fisheries education in India: history, current status and future-a review. Int J Curr Microbiol App Sci 7(6):3395–3409

Liou WK, Chang CY (2018) February. Virtual reality classroom applied to science education. In: 2018 23rd international scientific-professional conference on information technology (IT). IEEE, pp 1–4

Maculewicz J, Świacka K, Kowalska D, Stepnowski P, Stolte S, Dołżonek J (2020) In vitro methods for predicting the bioconcentration of xenobiotics in aquatic organisms. Sci Total Environ 739:140261

Malchi T, Eyal S, Czosnek H, Shenker M, Chefetz B (2022) Plant pharmacology: insights into in-planta kinetic and dynamic processes of xenobiotics. Crit Rev Environ Sci Technol 52(19): 3525–3546

Martínez FP (2011) Presente y Futuro de la Tecnología de la Realidad Virtual. Creatividad y sociedad 16:1–39

Mikropoulos TA, Strouboulis V (2004) Factors that influence presence in educational virtual environments. Cyberpsychol Behav 7(5):582–591

Mishra VK, Singh G, Shukla R (2019) Impact of xenobiotics under a changing climate scenario. In: Climate change and agricultural ecosystems. Woodhead Publishing, pp 133–151

Mohapatra S, Kumar R, Sundaray JK, Patnaik ST, Mishra CSK, Rather MA (2021) Structural damage in liver, gonads, and reduction in spawning performance and alteration in the haematological parameter of Anabas testudineus by glyphosate-a herbicide. Aquac Res 52(3): 1150–1159

Morina N, Ijntema H, Meyerbröker K, Emmelkamp PM (2015) Can virtual reality exposure therapy gains be generalized to real-life? A meta-analysis of studies applying behavioral assessments. Behav Res Ther 74:18–24. https://doi.org/10.1016/j.brat.2015.08.010

Opriş D, Pintea S, García-Palacios A, Botella C, Szamosközi Ş, David D (2012) Virtual reality exposure therapy in anxiety disorders: a quantitative meta-analysis. Depress Anxiety 29(2): 85–93. https://doi.org/10.1002/da.20910

Ortiz P, Torres-Sánchez A, López-Moreno A, Cerk K, Ruiz-Moreno Á, Monteoliva-Sánchez M, Ampatzoglou A, Aguilera M, Gruszecka-Kosowska A (2022) Impact of cumulative environmental and dietary xenobiotics on human microbiota: risk assessment for one health. J Xenobiot 12(1):56–63

Panchuk D, Klusemann MJ, Hadlow SM (2018) Exploring the effectiveness of immersive video for training decision-making capability in elite, youth basketball players. Front Psychol 9:2315

Parmaxi A (2020) Virtual reality in language learning: a systematic review and implications for research and practice. Interact Learn Environ 31(3):1–13

Pestek A, Sarvan M (2020) Virtual reality and modern tourism. J Tour Futur 7(2):245–250

Singla JG (2021) Virtual reality based novel use case in remote sensing and GIS. Curr Sci 121(7): 958

Slater M (2003) A note on presence terminology. Presen Conn 3(3):1–5

Smart Farming is Ready for Augmented and Virtual Reality, https://www.agritechtomorrow.com/article/2020/11/smart-farming-is-ready-for-augmented-and-virtual-reality/12516

Sports, https://www.strivr.com/solutions/industries/sports/#:~:text=A%20Virtual%20Reality%20(VR)%20sports,best%20when%20it%20truly%20matters

Štefanac T, Grgas D, Landeka Dragičević T (2021) Xenobiotics—division and methods of detection: a review. J Xenobiot 11(4):130–141

Testa B (1955) The metabolism of drugs and other xenobiotics: biochemistry of redox reactions. Academic Press

Tonelli FCP, Tonelli FMP (2020) Concerns and threats of xenobiotics on aquatic ecosystems. In: Bioremediation and biotechnology, vol 3. Springer, Cham, pp 15–23

Uses of VR in Military Training, https://www.futurevisual.com/blog/uses-vr-military-training/

Van Eck NJ, Waltman L, Dekker R, Van Den Berg J (2010) A comparison of two techniques for bibliometric mapping: multidimensional scaling and VOS. J Am Soc Inf Sci Technol 61(12): 2405–2416

Vet Med Library Information: VR Anatomy, https://guides.lib.vt.edu/vetmed/vranatomy

Virtual Reality for the Entertainment Market: All You Need to Know to Make Investment Decisions, https://jasoren.com/virtual-reality-for-the-entertainment/

VR AR Content Creation Market Ecosystem. Trend, Revenue and growth rate analysis along with decision intelligence – All The Research

VR for Science: Drug Discovery and More in the Virtual World, https://www.labcompare.com/10-Featured-Articles/577506-VR-for-Science-Drug-Discovery-and-More-in-the-Virtual-World/

VR in manufacturing, https://www.xcubelabs.com/blog/the-applications-of-virtual-reality-in-the-manufacturing-industry/

Walcutt NL, Knörlein B, Sgouros T, Cetinić I, Omand MM (2019) Virtual reality and oceanography: overview, applications, and perspective. Front Mar Sci 6:644

Waltman L, Van Eck NJ, Noyons EC (2010) A unified approach to mapping and clustering of bibliometric networks. J Informet 4(4):629–635

Wang X, Sial MU, Bashir MA, Bilal M, Raza QUA, Ali Raza HM, Rehim A, Geng Y (2022) Pesticides xenobiotics in soil ecosystem and their remediation approaches. Sustainability 14(6): 3353

Webster R (2016) Declarative knowledge acquisition in immersive virtual learning environments. Interact Learn Environ 24(6):1319–1333

Zhao L, Deng J, Sun P, Liu J, Ji Y, Nakada N, Qiao Z, Tanaka H, Yang Y (2018) Nanomaterials for treating emerging contaminants in water by adsorption and photocatalysis: systematic review and bibliometric analysis. Sci Total Environ 627:1253–1263