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Bibliometric Survey on Reuse of Treated Wastewater for Agriculture

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ABSTRACT

The water is important for life after air but there is water shortage problem worldwide. The untreated wastewater pollutes fresh water resources. The reuse of treated wastewater for crop irrigation will reduce stress on freshwater and also provides nutrients. Wastewater had been reused for many generations, it was first discovered in 1973 and in continuation there onwards till today. The treated-wastewater reuse for irrigation of crops will reduce stress on freshwater and also provides nutrients. The main objective of this bibliometric study is analyze the research work done in the past in relation to wastewater treatment and its reuse. This paper also covers pros and cons of reuse of treated wastewater for agriculture. This survey shows majority of the publications are from Brazil followed by United States of America. The maximum publications related to reuse of treated wastewater are from conference and journals. It is also identified that the count of research articles per year increased dramatically after 2013. Environmental science is the leading subject area, followed by agriculture, engineering, chemical engineering, and medicine. It is to be noted that this research area had maximum funding from European Commission. This art-search shows minimal contribution of review papers. This bibliometric survey will help new researchers to understand summary of the existing work and identify thrust area. Thus, this bibliometric analysis spans over publications according to languages, as per their types, prominent authors, leading countries, publications per year, major funding sponsors, key affiliations, also it shows co-appearance among journals and keywords, authors and keywords, references and keywords etc. In a way it is full platter of information in terms of different research aspects related till date research carried out about treated wastewater reuse.

Keywords: Bibliometric Analysis, Treated Wastewater, Reuse, Agriculture

1. Introduction

The water is important for life after air but there is water shortage problem worldwide. The untreated wastewater pollutes freshwater resources. The treated wastewater reuse for irrigation of crops will reduce stress on freshwater and provides nutrients. Moreover, it is also an environmentally friendly option, avoids pollution, and eliminates potential health hazards (Martinez, Perez-Parra, & Suay, 2011). From many generations wastewater has been used. During the Bronze Age (3200–1100 BC), the first evidence of reuse of sewage was found in ancient Greek, as stored flushed latrine water in the chamber (Angelakis & Gikas, 2014). Paris is the first city that reused wastewater in four peri urban areas in 1872 (Tzanakakis, Paranychianaki, and Angelakis 2007) . After that, in 1897, the first irrigation using wastewater was done in Melbourne, Australia (Tzanakakis et al., 2014). In the 20th century, the United Nations and few European cities started the agricultural wastewater use (Restrepo and Jaramillo, 2017).

About 3000 BC in South Asia, and spread on its subcontinent management of Wastewater appeared following urbanization development in its early-history (Fardin et al., 2013). In 1872, a farm from Paris had been irrigated first time in the world with wastewater (Jaramillo and Restrepo 2017). At Taxila during the 3rd century BC, through earthenware drainpipes and through canalized out from the houses domestic wastewater was drained through pipes into soak-pits. The water management development began to spread in south-east India, during the 300 BC to 300 AD i.e., Sangam period. To irrigate paddy-fields, and to practice fishing in lotus ponds (Bijker, 2007), rainwater was stored in tanks. Soil was the media to treat wastewater in various localities during the entire history (Fardin et al. 2013). The Prevention and Control of Pollution authority promulgated Water Act in 1974 in India for challenges faced for disposal-related issues and to address wastewater treatment related matters. In those days one of the challenges associated was regulating disposal industrial trade effluents and of the sewages in the receiving bodies which are nearby considering rivers, lakes, estuaries, ocean as well as in the creak (Kumar and Asolekar, 2016).

Considering different studies done in Southeast-Asian countries like Pakistan, India and China, where sewage with industrial effluent (diluted or untreated) is mainly used for irrigation, observed that contaminated with Lead and Cadmium were the main metals which created health risks (Evans and Elgallal, Fletcher, 2016).

1.1 Wastewater key statements in India

Water is essential for life, and it has a significant connection with public health and environmental concern (Daramola et al. 2019). Moreover, advancements in agriculture, industry, and urban activities around water resources have affected aquatic ecosystems and also leads in to waterborne diseases (Zeinalzadeh and Rezaei 2017). Among the countries in the world India is one of the most water-stressed country and slowly moving towards severe water scarcity scenario with a 1544 m^3 per capita water availability per year (Renzetti, 2002). Acute water stress problems persist in many regions of the country. North and South Karnataka districts, in Andhra Pradesh Rayalseema district; Marathwada and Vidarbha regions in Maharashtra; Bundelkhand region of Uttar Pradesh and Western Rajasthan and Madhya Pradesh (Dhawan 2017).

Irrigated area (around 42 million ha), which is more than half of the total irrigated area is being irrigated by groundwater. The absence of capacity methodology, deficient framework, and improper water management has lead India to a circumstance where just 18-20% of the available water is used. India receives around 1183 mm rainfall yearly, out of which 75% is received in monsoon season (July to September). It leads to run off during monsoon and water stress problems in the rest of the year (Dhawan 2017).

1.2 Treated municipal-wastewater reuse status in India

There are 723 cities and towns of India with population of 50,000 and above. The wastewater treatment capacity in India is 22,963 million liters per day (MLD), which is just 37% of the total waste generated in Class I and II urban centers. Consequently, over 63% of the wastewater created in these two classes of urban networks and urban areas is released into water bodies or on land with no treatment. It leads to broad ecological contamination and expanding the opportunity of infection advancement among the population (CPCB Report 2016).

Moreover, untreated or partially treated wastewater is being released into surface water bodies, which pollutes about 80% of the nation's surface water. Figure 1 shows that five states as Maharashtra, Uttar Pradesh, Delhi, Tamil Nadu, and Gujarat generate around 50% of the total sewage in the entire country. Maharashtra generates 13% of the total sewage generation of the country (CPCB Report 2016).

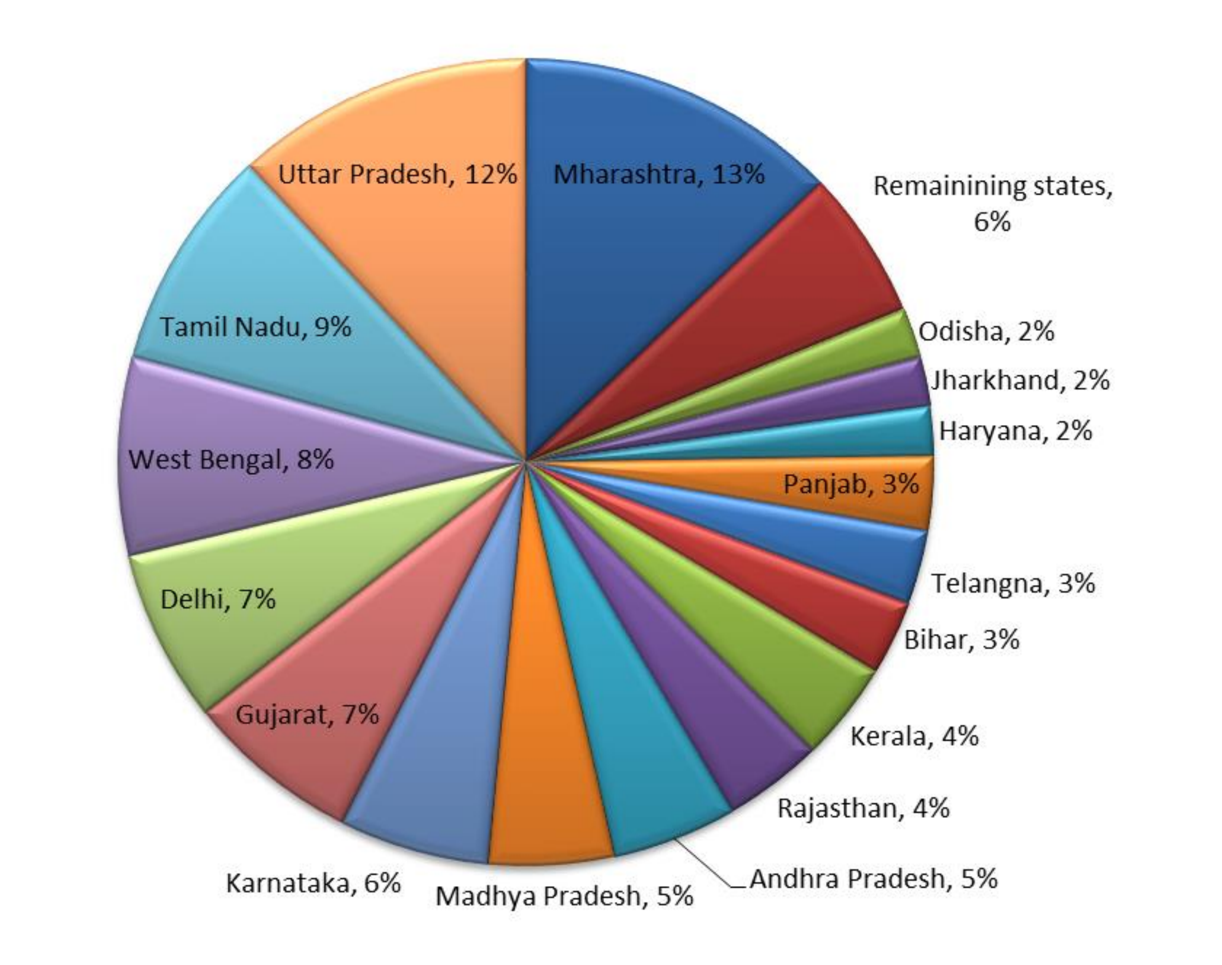

Fig 1 State wise percentage generation of sewage in India

(Source: Adapted from CPCB Report 2016)

An efficient way of managing water resources is treated wastewater reuse in agriculture. Heavy metals like mercury, lead, cadmium are toxic, and few of them are also of biomagnification kind (Karvelas, Katsoyiannis, and Samara 2003). Environmental and socioeconomic advantages of reuse of wastewater can be achieved if treatment technology eliminates the pollutants which are harmful to public health and to the environment (Moussaoui et al. 2019). The wastewater can be treated by using natural and artificial treatment methods.

1.3 Natural wastewater treatment methods

Natural wastewater treatment methods studied by Ham et al. 2007 as wastewater stabilization pond (WSP) and constructed wetland (CW). It was found that the average total phosphorus and total nitrogen rate of removal through WSP was approximately twenty-eight and twenty-five percentages, respectively. During the same span, the total phosphorus and total nitrogen rate of removal through the CW were twenty-three and thirty-one percentage, and for combo treatment system (constructed wetland and wastewater stabilization pond) rate of removal was about forty-six and fifty-one percentage, respectively. Results showed that CW and WSP systems are an efficient and feasible-alternative for reclamation of sewage in rural areas (which are decentralized in nature), and that it is cost-effective with low maintenance. (Hawary and Shaban 2018) compared the efficiency of three different plant species as duckweed (DW), water hyacinth (WH), and reed (RD) from Egypt. The wetland is constructed on Bahr El-Baqar drain. This agricultural drain is a highly polluted. The pollutants removal efficiency of RD (Reed) plants is higher than other plants. The micro-organisms from stems of RD breakdowns the organic matter. In addition to this, the bacteria's grow around the RD roots producing oxygen, which improves the treatment process. The average annual cost estimated for the RD, WH and DW for plantation, harvesting, and disposal were $1.25, $6.17 and $6.17 per cubic meter, respectively.

(Shelef, Gross, and Rachmilevitch 2013) observed the function of plants in a constructed wetland. It is revealed that halophytic plants like Bassia Indica eliminates salinity by absorbing salts in their tissues. Sodium accumulates more in shoots than the roots of the plants. Authors also mentioned that Phytoremediation is significant in CW. Evapotranspiration is 7-8 times more than actual evaporation without plants. The main components of the CW are water, media, microbes, and vegetation. Plants or vegetation from constructed wetland reduces the flow velocity of water which supports for sedimentation. Typha species can be grown as construction material fibers and like a bioenergy source as well. It also reduces wind velocity, eliminates pathogens, controls odor, and improves the aesthetic appearance of the system. It also has cons as loss of water increases through evapotranspiration and enhances mosquito reproduction. Through a combo of physical conditions of plants and contaminants as the accumulation of H_2O_2 which is a marker for plant stress, plants may act as a bioindicators.

(Page et al. 2010) focused on the estimation of removal efficiencies of herbicides for constructed wetlands. These herbicides, like diuron and simazine, are hazardous and present in the urban stormwater. The composite water sampling was done for water quality monitoring. This project is located in the city of Adelaide at Parafield airport in Australia. The area of the site is 0.11 km^2 with a water depth of 30 to 60 cm (standing). It consist of different species of reeds. The hydraulic retention time of wetland is seven days. The flow at outlet and level of water was measured. The wetland was designed to have a constant volume of approximately 21000 m^3 with an average depth of 0.2 m. Mean estimated concentrations over 28 days were 192 and 70 nanogram (ng) per lit through the inlet, 94 & 30 ng per lit through the outlet for the diuron and the simazine, respectively. The removal efficiency is

33–51% for diuron and 20–60% for simazine. (Shelef et al. 2011) planted sixteen plant species in a row on three different constructed wetland beds. Plant performance was measured by photochemical efficiency, CO_2 assimilation rate and cell membrane stability. There was a temporal improvement in the plants and it was correlated for different plant species. Wastewater flows through the sequence of beds, and sedimentation and biogeochemical processes take place. Six different water quality parameters were considered. It has been observed that all these parameters as BOD, COD, TSS, TN, TP and ammonia were diminished. The Canna lily is the plant species that responded to all the measures such as cell membrane stability, photochemical efficiency and photosynthesis rate so it is the most preferred bioindicator for water quality. (Shutes 2001) discussed the importance of plants to remove pollutants from wastewater through wetlands. The common reedmace (Typha latifolia) and reed (Phragmites australis) found to be the most effective from a range of aquatic plants (macrophytes) in breaking down the human and animal-derived wastewater. Therefore, from the review it is understood that the constructed wetland is found suitable and efficient to be used, either alone or in combination with other systems. Understanding the agricultural impacts of usage of treated wastewater for agriculture is also important.

1.4 Artificial wastewater treatment methods

(Xiaoye et al. 2018) have combined AnMBR i.e., Anaerobic Membrane Bioreactor with MD i.e., Membrane Distillation to treat the wastewater. The combined technology produced 0.3 to 0.5 L/g COD with methane 65%. The integration of AnMBR and MD improves removal efficiency of nutrients and organic load. The overall efficiency of the combined system was around 76%. Ozone used as a strong disinfectant to inactivate pathogens (Martínez et al. 2011). It has high oxidation potential and converts wastewater to water suitable for irrigation. The analysis shows that this treatment method reduces 68% of BOD5, 88% of COD, and also eliminates suspended solids up to 75%. It has been concluded from the results that ozone-treated water is good for agriculture. (Karvelas et al. 2003) implemented a standard method of water treatment plant (WTP) to treat wastewater of urban areas. The heavy metals as Ni, Mn, Pb, Cu, Zn, Fe and Cd were observed at six sampling points of WTP. It was found that more than 70 % of Mn and Cu were present through sludge and around 47 to 63% of Zn, Pb, Cr, Fe, Ni and Cd were observed through the treated effluent. The Fe was present in large amounts, followed by Zn. The Zinc was present in a more substantial amount at initial, secondary, and resultant sludge. The Cd was minimal as compared to other metals. Cu and Mn was filtered out at the primary stage, mainly Fe was filtered out with the effluent, and presence of other heavy metals was the same in sludge stream and effluent stream, these were the observations.

1.5 Reuse of treated wastewater for agriculture

(Paudel et al. 2018) applied treated wastewater for citrus and compared the effects of Treated Wastewater (TWW) and Fresh Water (FW). The parameters like water uptake, production, plant water, mineral, and vegetative growth of the citrus tree was taken into account. The organic load, Total Suspended Solids (TSS), and salinity was high in FW and TWW. Values of Arsenic were more for the soil irrigated in FW in comparison to TWW. No differences between stem water and sap flow water potential was found for freshwater and treated wastewater. The physical, as well as chemical properties of the soil, were also observed. The TWW has high SAR in comparison with FW so affects severely on soil structure results in to reduction of porosity and hydraulic conductivity. Moussaoui *et al.* (Moussaoui et al. 2019) did a physicochemical analysis for wastewater and soil. The physicochemical analysis includes parameters like Total Kjeldahl Nitrogen (TKN), Total Suspended Solids (TSS) and Biological Oxygen Demand (BOD), nitrate (NO_3), nitrite (NO_2), Total Phosphorus (TP), Chemical Oxygen Demand (COD) and orthophosphate. Soil physicochemical analysis was performed according to standard analytical methods. Treated wastewater reuse is a solution for water scarcity problem, develop local products, improve soil fertility, save natural resources and increase living standard of farmers.

(Huibers and Van Lier 2005) Water chain approach utilized for the use of scarce resources such as nutrients and water adequately. It connects different issues and domains of various disciplines in a logical and stepwise framework. Treatment of sewage is divided as initial, second level and third level treatments. The initial treatment eliminates coarse material, suspended solids by floatation and settlings. Secondary treatment removes organic matter by bacteria or biological actions. Tertiary treatment includes the filtering out of nutrients and pathogens by chemical, photochemical, and biological action. Treated wastewater reuse for agriculture has connection with many parameters such as water quality, hydrology, food production, health and socioeconomic issues. A water chain approach is a useful tool to bring the proper interdisciplinary in future research, plan, and policymaking.

(Jimenez 2005) developed Advanced Primary Treatment (APT) consist of a coagulation-flocculation process coupled with high-rate sedimentation. It has pros as well as cons but regulation and appropriate wastewater technology may help to reduce the risk of reuse of wastewater. The reuse of wastewater minimizes the cost of fertilizer as it consists of nutrients needed for crop. The application of treated wastewater may cause heavy metals accumulation into the soil, non-intentional aquifer recharge, an increase in soil salinity and diarrheal diseases. Following are the advantages and disadvantages of treated wastewater reuse for agriculture.

Table 1 Advantages and Disadvantages of Treated Wastewater Reuse for Agriculture

Sr. No.	Treated Wastewater Reuse for Agriculture		**Citations**
	Pros	**Cons**	
1	Improves soil fertility	Soil structure damages which reduces water uptake	(Moussaoui et al. 2019)
2	No effect on fruit quality if compared with fresh water	Reduces plant vegetative growth and yield	(Paudel et al. 2018)
3	Improves living conditions of farmers and also preserves natural resources	Toxic level increases because of accumulation of Na and Cl to root and leaves of crop	(Moussaoui et al. 2019)
4	It reduces cost of fertilizer and farm profitability	Absorption of heavy metals by food crops	(Elgallal et al. 2016)
5	It fulfils requirement of nitrogen and phosphorous.	Soil salinity increases with time at greater rate by treated wastewater than freshwater.	(Ganjegunte et al. 2017)
6	It also reduces stream or river pollution	Plant can damage if chlorine residual is more than 5 mg/lit for sprinkler irrigation.	(Pedrero et al. 2010)
7	It does not reduce the yield of the crop	Clogging problems in sprinkler and drip irrigation	(Ham et al. 2007)

While many studies have discussed these issues, there is limited bibliometric analysis that condenses these findings. This paper presents a bibliometric analysis of treated wastewater reuse for agriculture, section two shows primary level of data collection about treated wastewater reuse for agriculture publications; section three presents detailed bibliometric exploration. Section 4 and 5 discusses further scope and limitations of the carried out research respectively followed by conclusions in the section 6 followed by references at the last.

2. Data Collection at Preliminary Level

Open access and paid access are two types of access to the publication databases namely. (Sarmiento and Nagi 1999). Access to these publications can be through university library portals or through registering on individual websites of databases. To retrieve the data from required databases, there are different popular ways. Google Scholar, Clarivate, SCImago, Scopus, ScienceDirect, Mendeley, DBLP and ResearchGate etc. are popular publication databases. Large number of abstracts and citations to them for peer reviewed papers from the field of engineering, science, technology, medicine, arts, social science and humanities are in the Scopus database. Section 2.1 contains papers extracted from the Scopus database based on significant keywords.

2.1 Important Keywords

The important keywords related to reuse of treated wastewater for agriculture were used for Scopus database search. The publication count varies from 29 to 1535 depending upon combination of different keywords. The final count of 138 publications have been selected for bibliometric analysis.

Table 2 Planned search tactic for Keywords

Sr. No.	Keywords	Publication Count
1	"Treated wastewater" AND "reuse" AND "agriculture"	441
2	Reuse of treated wastewater AND "agriculture"	97
3	Treated wastewater AND "agriculture"	867
4	Treated wastewater AND "irrigation"	1535
5	Reuse AND "treated wastewater" AND "irrigation"	742
6	Reuse AND "treated domestic wastewater" AND "irrigation"	29
7	Treated domestic wastewater AND "irrigation"	67
8	Treated domestic wastewater AND "irrigation" OR "reuse"	84
9	Reuse AND "treated domestic wastewater" AND "irrigation" OR "agriculture"	34
10	Reuse AND "treated domestic wastewater" AND "irrigation" OR "agriculture" OR "constructed wetland"	34
11	Treated domestic wastewater AND "irrigation" OR "agriculture" OR "constructed wetland"	90
12	"Treated domestic wastewater" AND "irrigation" OR "agriculture"	71
13	"Treated domestic wastewater" AND "irrigation" OR "agriculture" OR "constructed wetland" OR "reuse"	108
14	Treated domestic wastewater AND "irrigation" OR "Agriculture" OR "Constructed Wetland" OR "reuse" OR "municipal wastewater"	114
15	"Treated domestic wastewater" AND "irrigation" OR "Agriculture" OR "Constructed Wetland" OR "reuse" OR "municipal wastewater" OR "Nutrient"	138

(Source: Scopus website accessed on 13th January 2021)

2.2 Language trends

The research papers are extracted from Scopus database. Initial level analysis is through keywords planned, and their search-tactic generated in total 138 publications. 122 publications are in English and this study is restricted to them only as shown in Table 3.

Table 3 Reuse of treated wastewater publishing language patterns

Sr. No.	Language	Paper Count
1	English	122
2	Portuguese	13
3	Chinese	3
4	French	1
5	Spanish	1
	Total	138

3. Bibliometric analysis

The in depth bibliometrics analysis is done in third section to get the idea about prominent researchers, literature in the field of reuse of wastewater in agricultural area through research considering attentiveness about geographical locations, affiliative statistics, contributions of author, key journals wherein papers have been published and their related statistics, in addition to citation analysis and studies in collaboration. Two parts of this bibliometric analysis is there – they are general and network diagrams.

3.1 General diagrams related to bibliometric analysis.

Following are the general diagrams for bibliometric analysis which includes document count on the basis of year, author, source, funding agencies, affiliation and country.

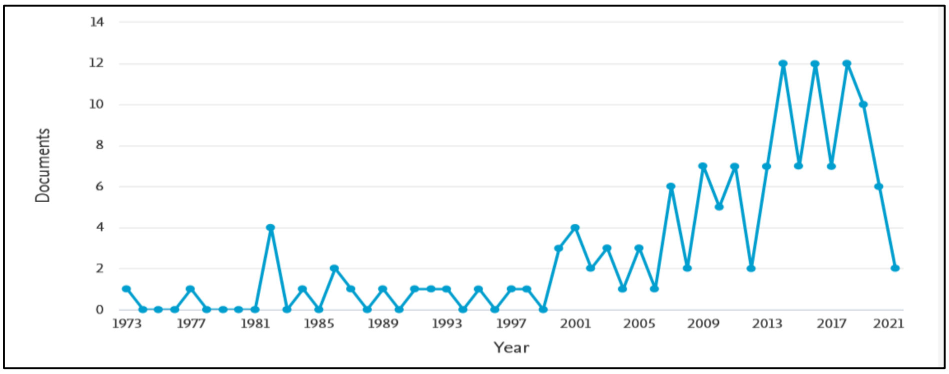

Fig. 2 Documents by year

(Source: Scopus website accessed on 13th January 2021)

Fig. 2 shows year wise documents. The key observations from fig. 2 are as mentioned below:

The Year span is from 1973 to 2021.

1) Till 1973 to 1977 – publication count is very less,
2) From 1981 till 2008 – this research area gained 50% momentum,
3) From 2009 till 2013 – this research area gets paid attention,
4) After 2013 till 2021 – number of publications related to this area get increased.

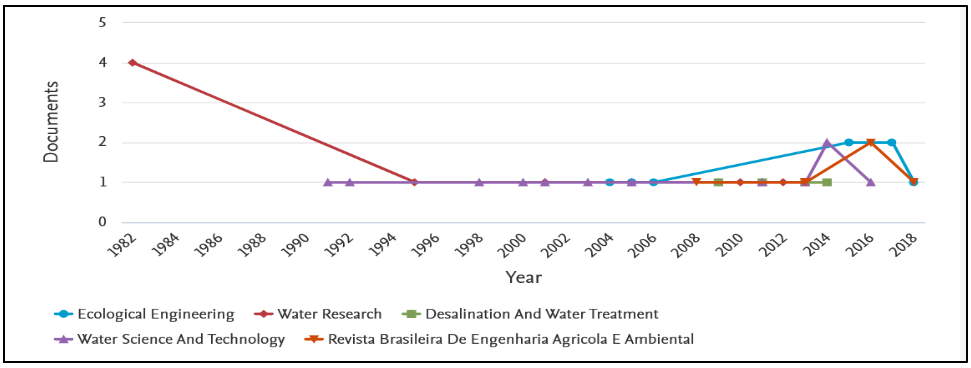

Fig. 3 Documents per year by source

(Source: Scopus website accessed on 13th January 2021)

Fig. 3 shows documents related to source per year. Observations from this figure are as follows:

1) More number of documents are published in Water Research,
2) From 1992 to till 2016, every year documents are published in Water Science and technology,
3) 2006 to 2018 documents were published in Ecological Engineering,
4) 2008 to 2018 documents were published in Revista Brasileria De Engenharia Agricola E Ambiental,
5) From 2010 to 2014 documents were published in Desalination and Water Treatment.

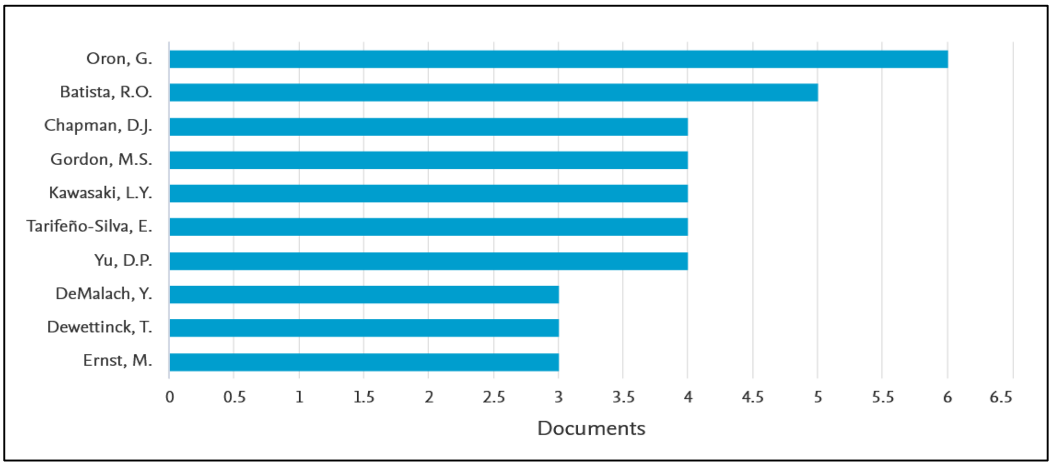

Fig. 4 Documents by author

(Source: Scopus website accessed on 13th January 2021)

Fig. 4 indicates following key points.

1) Oron, G. and Batista, R. O. are the prominent authors having 6 and 5 publications respectively against their name,
2) Other authors have 4 and 3 publications against their name,
3) So, there is a lot scope for research in the considered area.

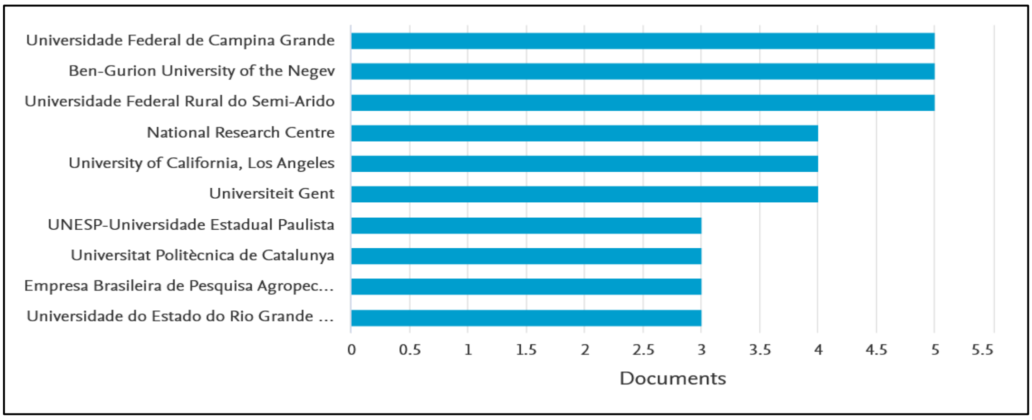

Fig. 5 Documents by affiliation

(Source: Scopus website accessed on 13th January 2021)

Fig. 4 and fig. 5 are interrelated. As the count specified in these figures is somewhat similar. Here also,

1) First three affiliations have 5 documents related to them each,
2) Next three affiliations have 4 documents related to them,
3) and the last four affiliations have 3 documents related to them.

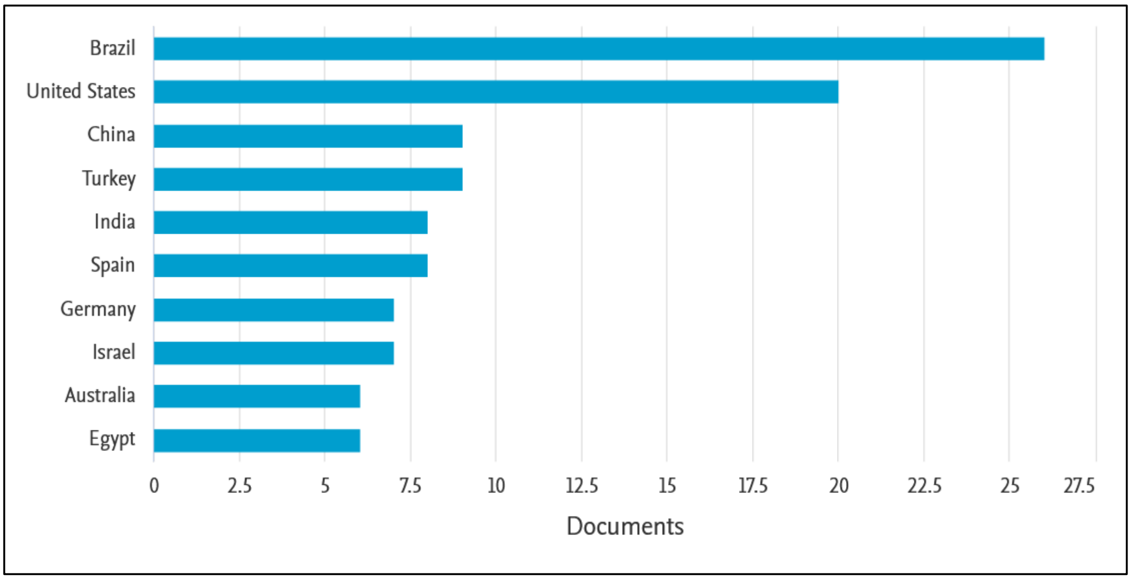

Fig. 6 Documents by country or territory

(Source: Scopus website accessed on 13th January 2021)

Fig. 6 denotes,

1) Brazil has 26 publications and Unites State has 20. This indicates that these countries are leader in the considered research area,
2) Other countries have less than 10 publications in their account,
3) So, there is a lot of scope for research in the undertaken research in India.

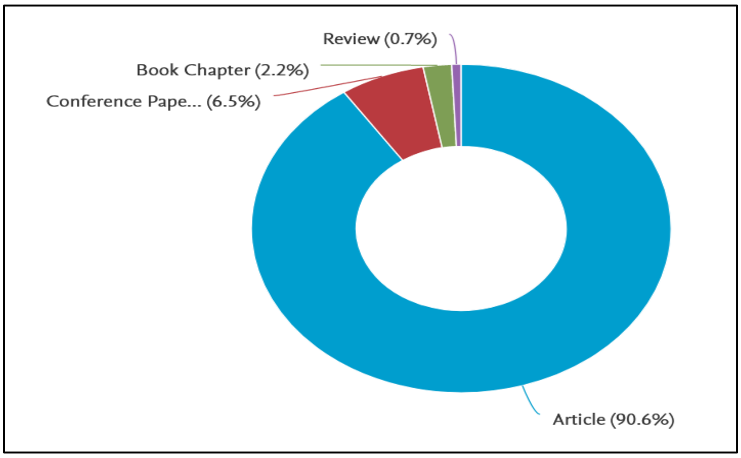

Fig. 7 Documents by type

(Source: Scopus website accessed on 13th January 2021)

Fig. 7 shows

1) Majority of the publications are of article type,
2) Follow to this, conference papers and book chapter are the publication types,
3) Very less contribution in terms of review paper that's why this is the research paper.

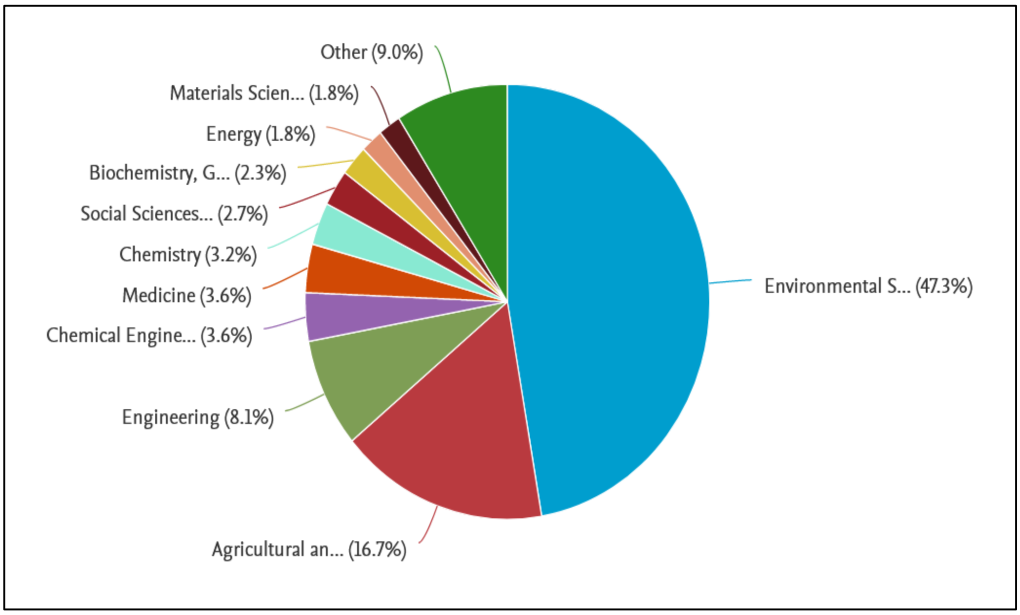

Fig. 8 Documents by subject area

(Source: Scopus website accessed on 13th January 2021)

1) Environmental science is the leading subject area,
2) Followed to this agriculture, engineering, chemical engineering, medicine, chemistry, social science, biochemistry, energy, material science are the subject areas.

These are the observations from the fig. 8. It shows that interdisciplinary areas are also involved in the undertaken research.

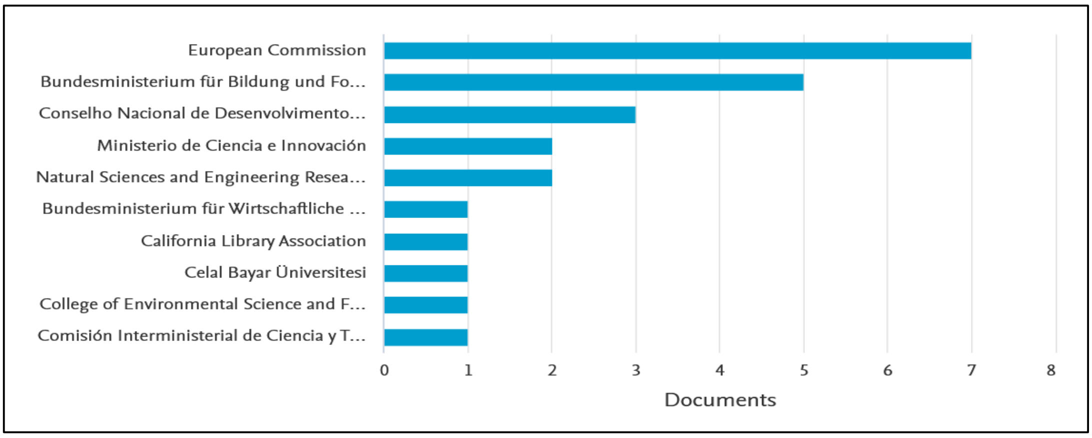

Fig. 9 Documents by funding sponsor

(Source: Scopus website accessed on 13th January 2021)

Fig. 9 shows that this research area also gets funding from different funding agencies. It in a way shows utility of the considered research area. So, considered research area need to be paid more attention.

3.2 Networked diagrams related to bibliometric analysis

Fig. 10 to 116 shows details about co-appearance related to the following entities.

1) Authors and their keywords,
2) Authors and related source titles,
3) Source titles and author keywords,
4) Authors linked through their publications and
5) Author keywords co-appearance

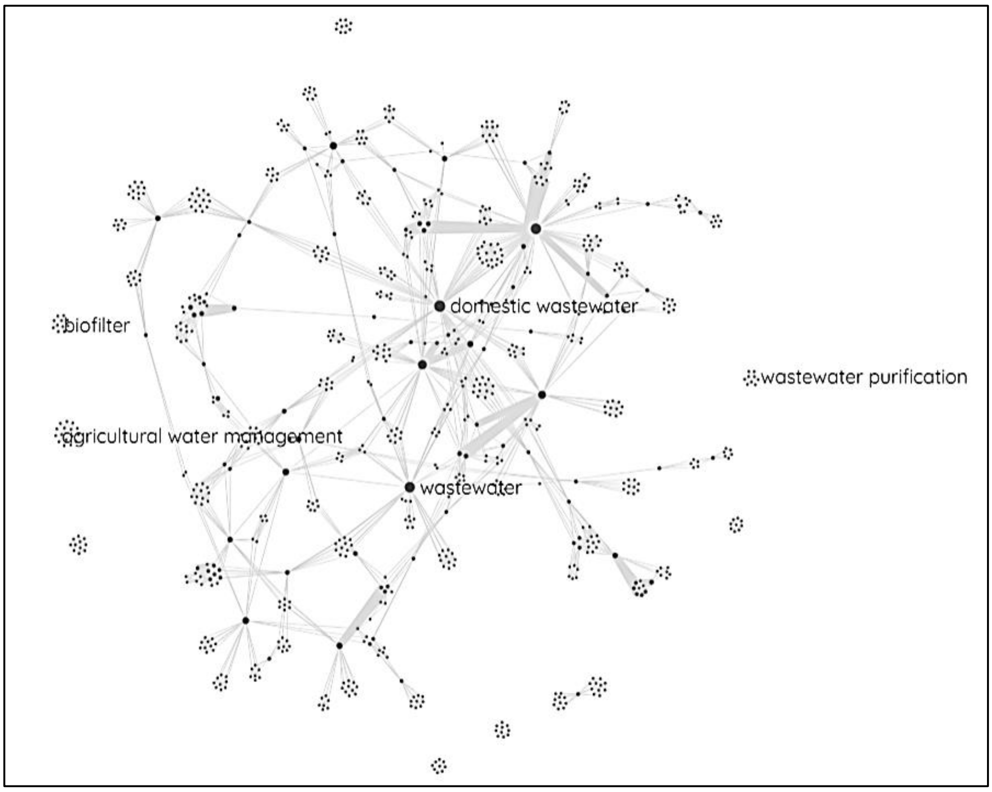

Fig. 10 Co-appearances of author keywords

(Source: ScienceScape (medialab.github.io) accessed on 13th January 2021)

Co-appearances of keywords can also signify scope of the undertaken research. Following are the keywords shows the co-appearance.

1) Domestic water
2) Biofilter
3) Wastewater and wastewater purification and
4) Agriculture management.

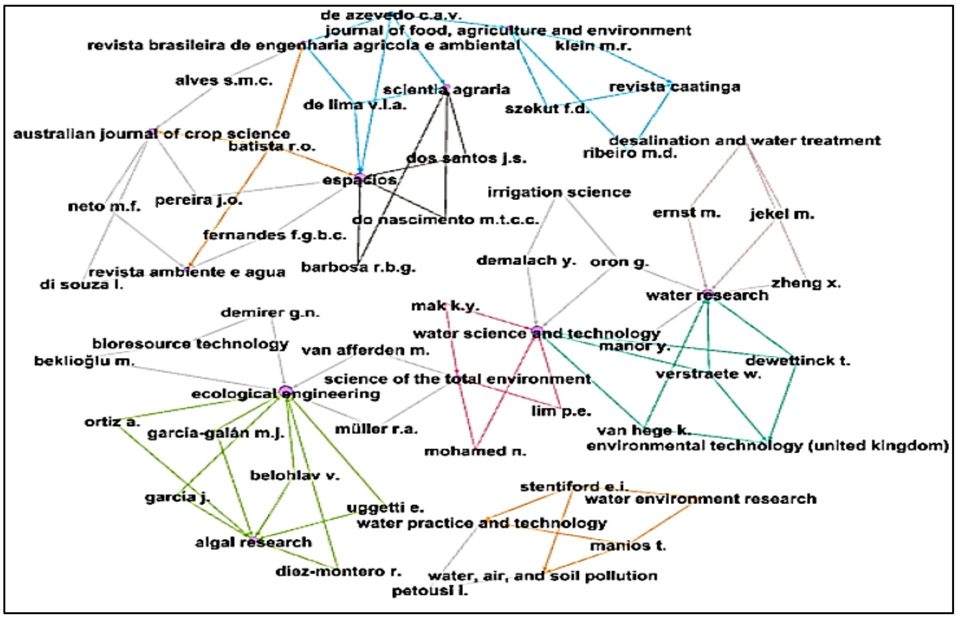

Fig. 11 Co-appearances of authors and source titles

(Source: Gephi.com accessed on 13th January 2021)

Here are some of the examples related to the co-appearances of authors and source titles from fig. 11 are as follows:

1) Stentiford e. i. and Manios t. are related to Water Environment Research and Water, Air and Soil Pollution,
2) Lim p. e., Mohamed n., Mak k. y. are related to the Water Science and Technology and
3) Szekut f. d. and Klein m. r. are related to the Journal of food, agriculture and environment.

Through these examples other co-appearances related to authors and source titles can be easily identified.

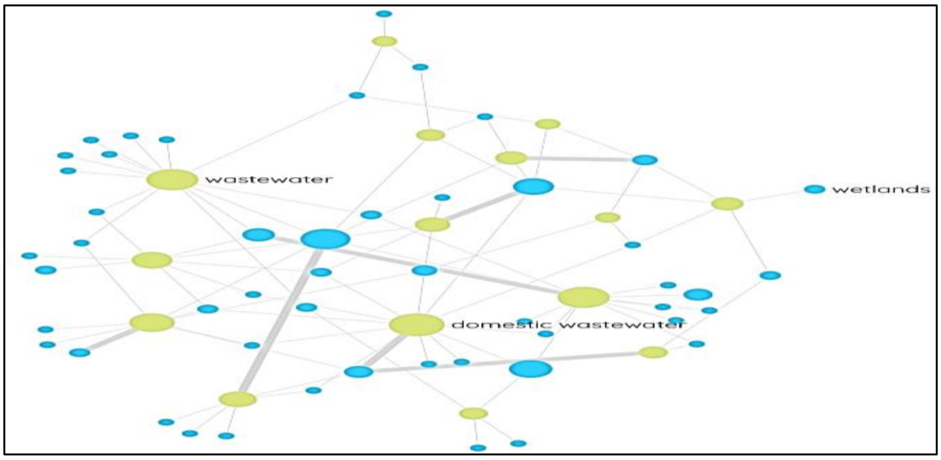

Fig. 12 Co-appearances of keywords and source titles

(Source: MiniVan. Mathieu Jacomy, Guillaume Plique, Robin de Mourat, Arnaud Pichon, Axel Meunier (2018-03-14) | médialab Sciences Po accessed on 13th January 2021)

Fig. 12 is quite related to the fig. 10. In addition to the keywords identified in fig. 10, following are the additional keywords that came out through the fig. 12. They are as follows:

1) Wetlands
2) Domestic Wastewater

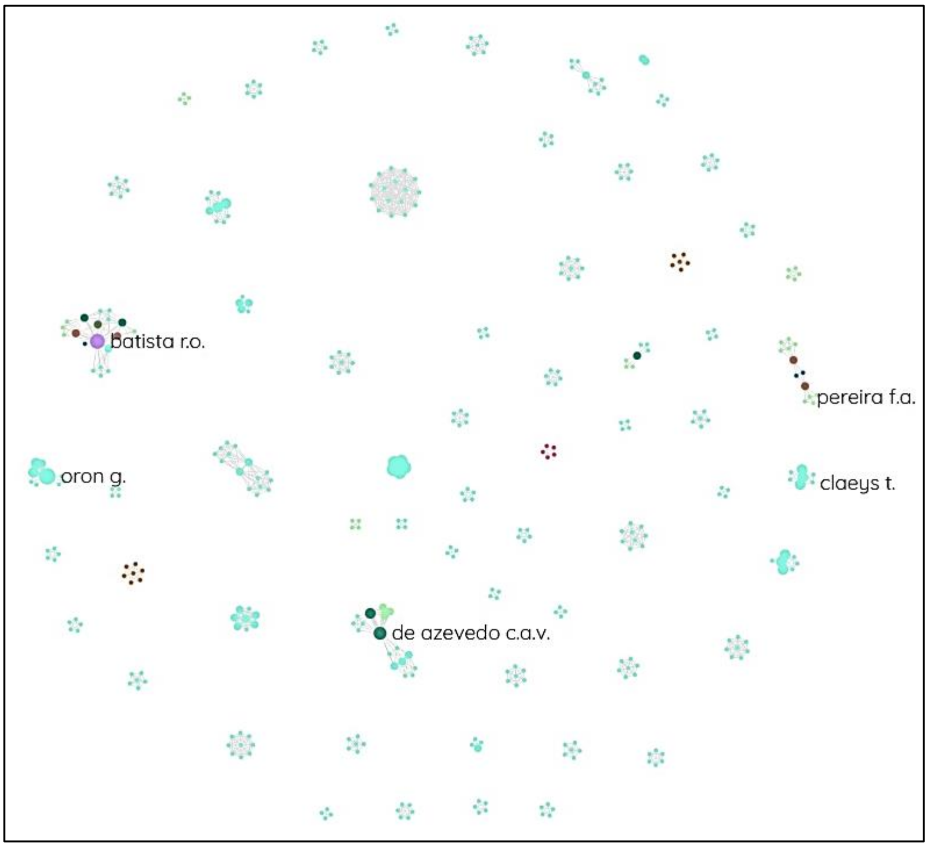

Fig. 13 Authors linked by co-publications

(Source: MiniVan. Mathieu Jacomy, Guillaume Plique, Robin de Mourat, Arnaud Pichon, Axel Meunier (2018-03-14) | médialab Sciences Po accessed on 13th January 2021)

Fig. 13 is related to the fig. 10. From these two figures one can easily get the idea of the authors who are related to each other their co-publications. They are as follows:

1) Batista r. o.
2) Oron g.
3) Pereira f. a.
4) Claeys t.
5) De azevedo c.a.v. are the authors related through their co-publications.

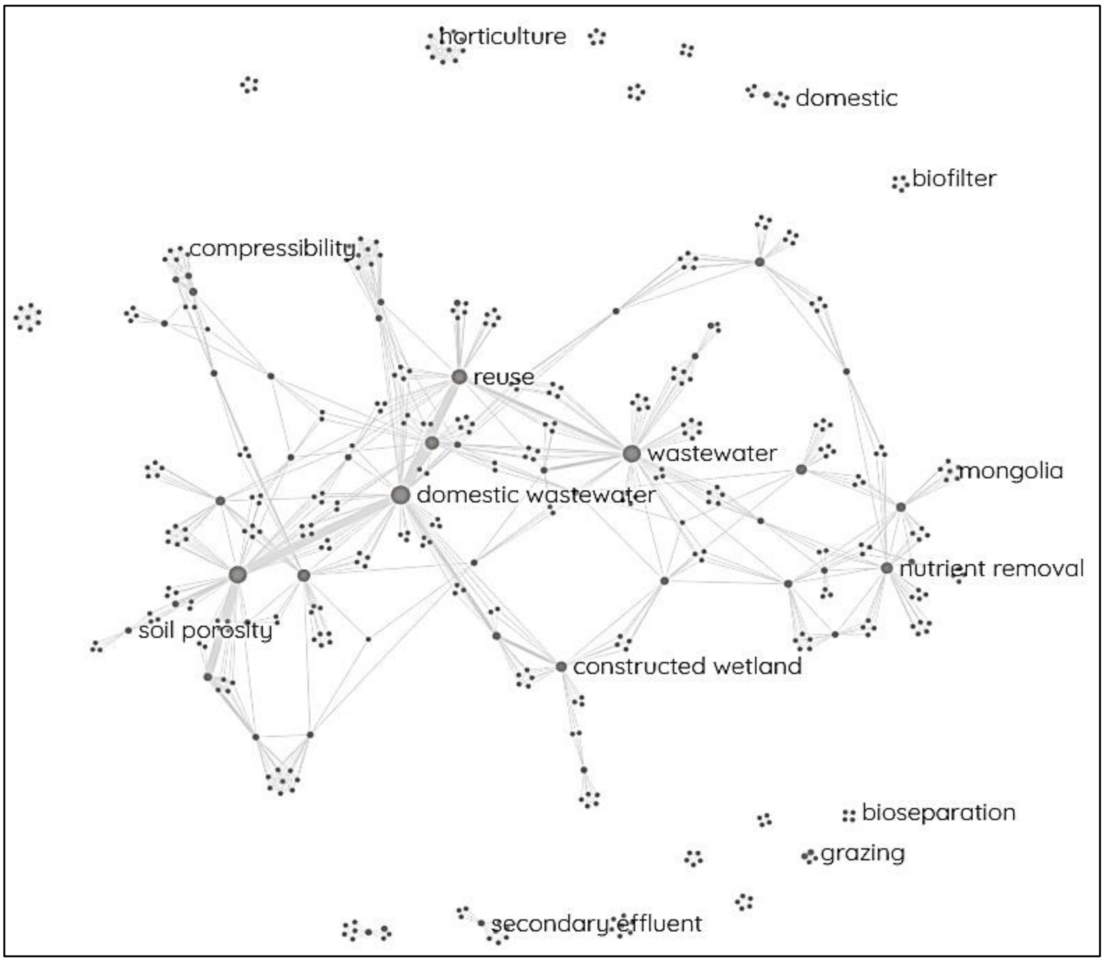

Fig. 14 Co-appearances of author keywords

(Source: ScienceScape (medialab.github.io) accessed on 13th January 2021)

Fig. 14 again adds few more additional keywords to the undertaken research in addition to the keywords identified through earlier bibliometric analysis. They are as follows:

1) Constructed wetland,
2) Secondary effluent,
3) Grazing,
4) Bioseparation,
5) Nutrient removal,
6) Soil porosity,
7) Reuse,
8) Compressibility and
9) Horticulture

So, these additional keywords specify further aspects related to the considered research.

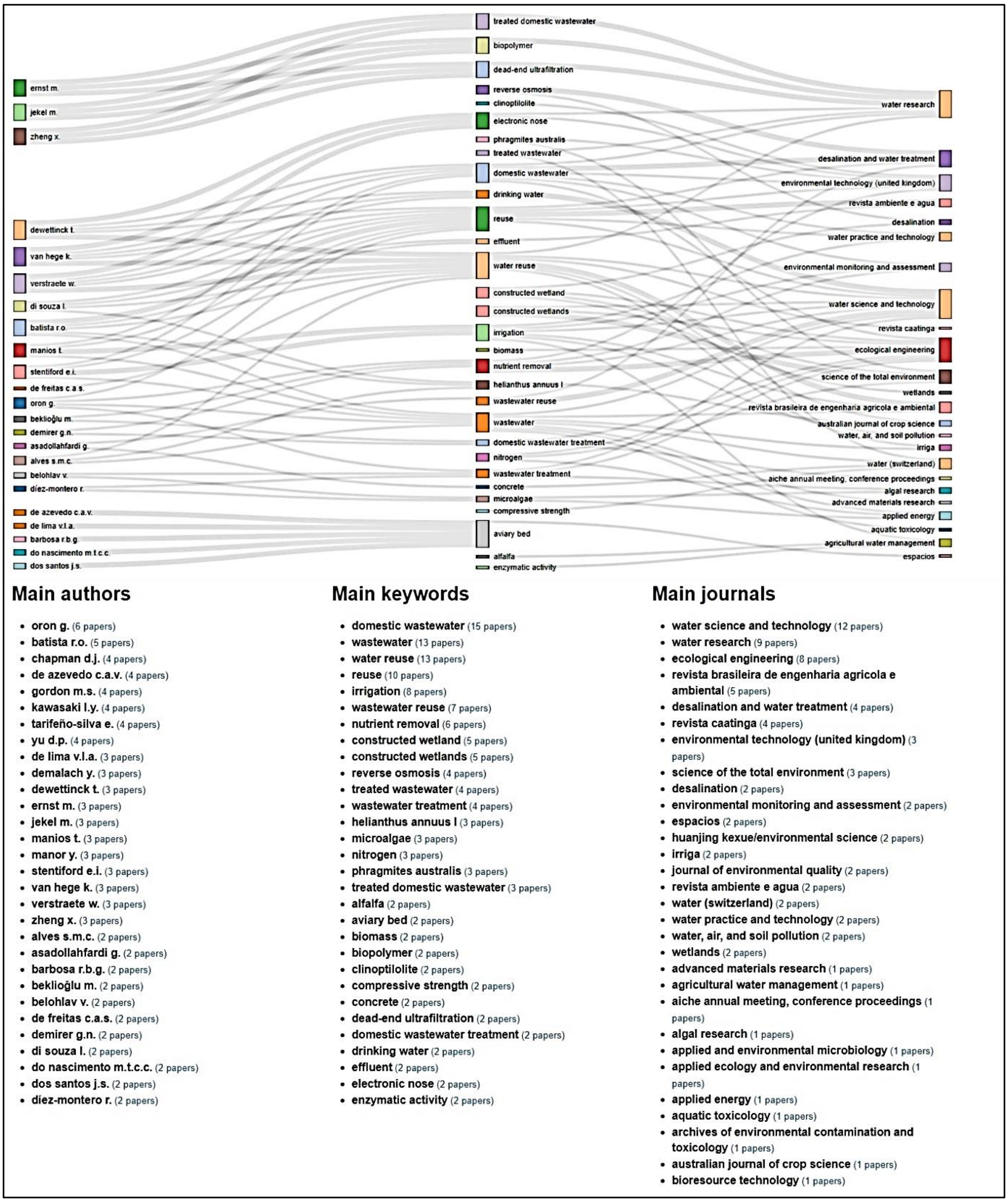

Fig. 15 Main authors-Main keywords-Main journals Sankey

(Source: ScienceScape (medialab.github.io) accessed on 13th January 2021)

Fig. 15 in a way summarizes and validates details obtained through the fig. 10 to 14. This fig. is self-explanatory. One can easily get an idea about three entities viz. main authors, main keywords and main journals from fig. 15.

In addition to the details identified from fig. 2 to 15, fig. 16 shows important references related to the undertaken research. In a fig. 16 is important as these references can be an important aspect while formulation the new research related to the considered research area.

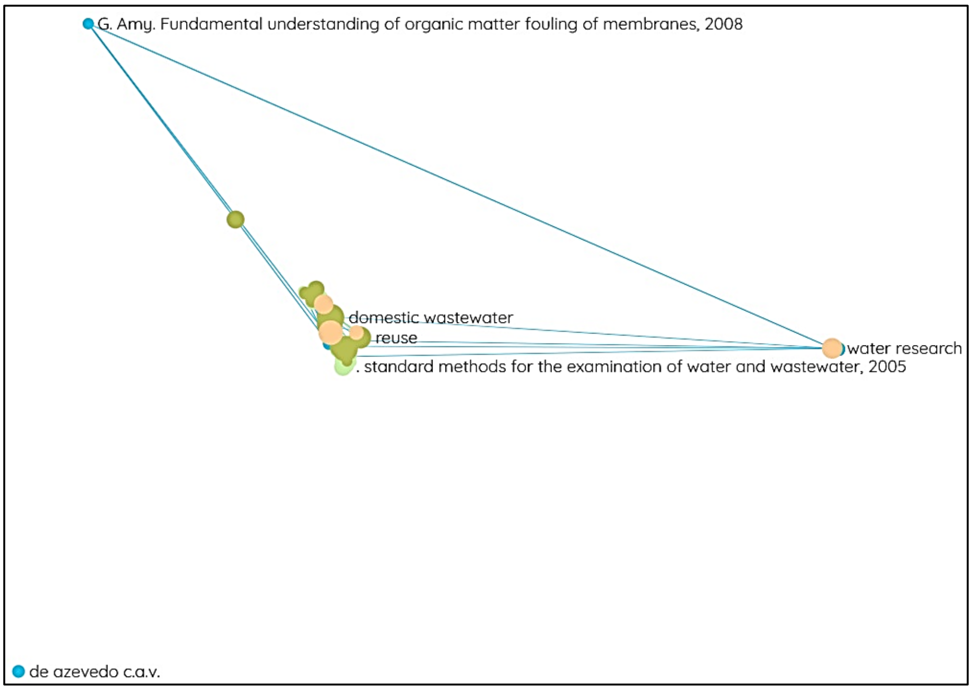

Fig. 16 References Scape

(Source: ScienceScape (medialab.github.io) accessed on 13th January 2021)

From fig. 16 it is clear that one can get an idea about the keywords and related references. So, in a way this fig. will be useful so that new authors who want to something in this research area can consider details in terms of keywords and related references.

4. Research implications of the carried-out study

Treated wastewater reuse is a trending topic. The carried out bibliometric study shows breadth and width of the undertaken research in terms of involved authors, countries, funding sponsors, affiliations etc. The carried out bibliometric gives an overview about the current state of the considered research. The obvious implications that came out of this bibliometric study is that there is a lot of scope towards extension to the already existing research in the considered research area. Indian universities, and research centers may take a lead in doing so, also there is very minimal contribution in terms of review papers that's why this bibliometric study was carried out. This study in a way that can act as a lighting tower in the ocean of reuse of treated wastewater research. The new emerging researchers can consider this bibliometric as a summary of the existing work, identification of lacking areas, these aspects can be taken ahead in order to achieve betterment of the undertaken research.

This bibliometric study identified that publications in English are prominent, there are publications in Portuguese language also. From 2013 to 2021, there is an increase in the number of publications. Water Research is the prominent source type. Domestic water, wastewater, industrial wastewater management are the co-appearing keywords. Water Environment Research and Water, Air and Soil Pollution, Water Science and Technology and Journal of Food, Agriculture and Environment are the co-appearing source titles. Domestic wastewater and wetlands are the keywords co-appearing among the source titles. Co-appearance of author keywords reveals additional aspects related to the considered research topic for bibliometric i.e., bio-separation, removal of nutrients, secondary effluents, compressibility etc. Sankey diagram gives tri-information viz. main authors, main keywords and main journals. Reference-scape shows co-appearance of keywords and references.

In a way this bibliometric is the summary of till date research and its extraction in terms of different research related aspects like authors, journals, keywords, their co-appearance. This research could be beneficial as a reference point to those who want to extend it to a further level and helpful to fresh researchers who want to do something new in this area.

The further steps or future scope is the use of this presented information in this research paper in terms of following the prominent authors, following the leading journal, most cited articles, co-appearing keywords while formulation a new related research in relation to the research topic under consideration.

5. Conclusion

This bibliometric study summarizes following key entities as it starts with the introductory details about different dimensions about treated wastewater and its reuse. It also shows what keywords need to be considered in order to fetch precise publications from Scopus database.

This paper also covers wide range of information like prominent authors, keywords, their co-publications, source titles. The co-appearance among these entities is also shown through network diagrams related to undertaken bibliometric study. This study consolidates every aspect related to research that is ongoing about reuse of treated waste water for agriculture.

This bibliometric survey on reuse of treated wastewater revealed that the count of research articles per year was increased dramatically after 2013. Oron, G. and Batista, R. O. are the prominent authors having 6 and 5 publications respectively against their name. Brazil has 26 publications followed to this US has 20. It indicates that these countries are leader in the considered research area. Environmental science is the leading subject area, followed to this agriculture, engineering, chemical engineering, and medicine. This research area that has maximum funding from European Commission.

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