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# Bibliometric Analysis of Aluminium Oxide Nanoparticle in Biomedical Applications

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**Abstract**. Aluminium oxide nanoparticles are materials that can be used in various applications, for example in biomedicine. The purpose of this study was to determine research trends on $Al_2O_3$ nanoparticles in biomedical applications using bibliometric analysis. The data used in this study was obtained from Google Scholar using the Publish or Perish reference manager and data visualization using VOSviewer. The data obtained were based on the keywords $Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, and biomedical application. Based on the analysis, we found 987 articles relevant to the keywords from 2012–2022. The results show that research on $Al_2O_3$ nanoparticles in biomedical applications from 2012–2022 tends to increase with the most articles in 2012, as many as 196 articles. This bibliometric analysis is expected to help other researchers who will conduct research on the same theme as discussed in this article.

**Keywords**: bibliometric, $Al_2O_3$ nanoparticle, biomedical application

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## 1. Introduction

Nanotechnology can be interpreted as the design, characterization, production, and application by controlling shape and size at the nanoscale (<100 nm). Modern nanotechnology can produce various metal or non-metallic particles in nano size which also called nanomaterials or nanoparticles with unique mechanical, optical, electrical, and magnetic properties [1], [2]. Alumina is an aluminium oxide compound with the formula $Al_2O_3$. $Al_2O_3$ nanoparticles are metal oxide materials and are included in nanomaterials with pores that are thermodynamically stable at various temperatures [3], [4]. $Al_2O_3$ is one of the most produced nano-sized chemicals, it is even estimated to reach 20% of all nanoparticle materials in 2005. There are various methods of synthesizing $Al_2O_3$ nanoparticles, there are precipitation, combustion, sol-gel, wet chemical, synthesis under supercritical water conditions, with microwaves, mechano-chemically, and hydrolysis [5].

$Al_2O_3$ nanoparticles are widely used in catalysts, ceramics, materials that can increase cement strength, polymer modification, textile functionalization, heat transfer fluids, and wastewater treatment [6], [7]. In addition, $Al_2O_3$ nanoparticles have also been investigated for various biomedical applications,

such as in drug delivery systems, biosensing, cancer therapy, anti-microbial effects, immunotherapy, and anti-bacteria [2], [3]. Beside that, high purity-$Al_2O_3$ nanoparticles can be used in bio-ceramic applications [8].

From this explanation, it can be seen that $Al_2O_3$ nanoparticles have various benefits in life. So, knowledge of research trends is needed for the development of applications of $Al_2O_3$ nanoparticles. Bibliometric analysis is a form of meta-analysis of research data that researchers can use to study bibliographic content and citation analysis from articles published in journals or other scientific works [9]. Bibliometrics can be used to evaluate research that has been conducted annually, both qualitatively and quantitatively. Visualization of bibliometric analysis is carried out using software, one of which is VOSviewer which is included in open source and free [10].

Bibliometric analysis has been carried out on various types of research, for example bibliometric analysis on research trends in drug delivery and magnetic nanoparticles [11]; cancer therapy using nanoparticles [12]; research progress on transition metals in biomedicine [13]; chitosan and PVC polymers in biomedical applications [14]; and silver nanoparticles in biomedical applications [15]. In addition, bibliometric analysis of nanoparticles has been carried out on the nanoparticles toxicity on algae [16]. However, until now, there has been no bibliometric analysis of $Al_2O_3$ nanoparticles in biomedical applications.

This study aims to determine research trends on aluminium oxide nanoparticles in biomedical applications during the period 2012–2022 using bibliometric analysis. In this analysis, the data obtained from Publish or Perish and visualized using VOSviewer software. This analysis is expected to be a reference for researchers to start appropriate research, especially those related to aluminium oxide nanoparticles.

## 2. Methods

In the Publish or Perish application, keywords are used in the form of "$Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, biomedical application". After obtaining various articles that containing these keywords, the article data that was publish in 2012–2022 is stored into *.ris format and *.csv format. The next step is visualization and analysis of research trends through mapping using VOSviewer [9]. VOSviewer is a software that can be used to create bibliometric maps by visualizing networks or relationships in citing an article [17]. There are three types of mapping performed during visualization using VOSviewer, namely network visualization, overlay visualization, and density visualization. Before the visualization is done, there are terms that can be selected according to the keywords used.

## 3. Results and Discussion

### *3.1. Publication data search result*

Based on the search results using the Publish or Perish application from the data obtained in Google Scholar, there were 987 articles that matched with the criteria. The data includes the title, author, year, number of citations, journal name, publisher, article links, and other data. The number of citations from all articles obtained was 26636. All articles obtained have an average h-index of 73 and a g-index of 135. **Table 1.** shows examples of article search results using Publish or Perish.

**Table 1.** $Al_2O_3$ nanoparticle in biomedical application publication data from Publish or Perish

| No. | Author | Title | Year | Number of citation |
|---|---|---|---|---|
| 1 | W Yu, H Xie | A review on nanofluids: preparation, stability mechanisms, and applications | 2012 | 1598 |
| 2 | SR Saptarshi, A Duschl, AL Lopata | Interaction of nanoparticles with proteins: relation to bio-reactivity of the nanoparticle | 2013 | 931 |

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| 3 | B Tanhaei, A Ayati, M Lahtinen, M Sillanpää | Preparation and characterization of a novel chitosan/$Al_2O_3$/magnetite nanoparticles composite adsorbent for kinetic, thermodynamic and isotherm studies of Methyl Orange adsorption | 2015 | 404 |
| 4 | GEJ Poinern, S Brundavanam, D Fawcett | Biomedical magnesium alloys: a review of material properties, surface modifications and potential as a biodegradable orthopaedic implant | 2012 | 328 |
| 5 | IM Hamouda | Current perspectives of nanoparticles in medical and dental biomaterials | 2012 | 249 |
| 6 | E Bajraktarova-Valjakova, V Korunoska-Stevkovska, B Kapusevska, N Gigovski, C Bajraktarova-Misevska, A Grozdanov | Contemporary dental ceramic materials, a review: chemical composition, physical and mechanical properties, indications for use | 2018 | 143 |
| 7 | MA Ansari, HM Khan, AA Khan, SS Cameotra, Q Sauib, J Musarrat | Interaction of $Al_2O_3$ nanoparticles with Escherichia coli and their cell envelope biomolecules | 2014 | 126 |
| 8 | DK Koli, G Agnihotri, R Purohit | Properties and characterization of Al-$Al_2O_3$ composites processed by casting and powder metallurgy routes | 2013 | 125 |
| 9 | P Samal, PR Vundavilli, A Meher, MM Mahapatra | Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties | 2020 | 120 |
| 10 | PA Prashanth, RS Raveendra, RH Krishna, S Ananda, NP Baghya, BM Nagabhushana, K Lingaraju, HR Naika | Synthesis, characterizations, antibacterial and photoluminescence studies of solution combustion-derived α-$Al_2O_3$ nanoparticles | 2015 | 115 |
| 11 | M Jama, T Singh, SM Gamleldin, M Koc, A Samara, RJ Isaifan, MA Atieh | Critical review on nanofluids: preparation, characterization, and application | 2016 | 115 |
| 12 | SZ Heris, TH Nassan, SH Noie, H Sardarabadi, M Sardarabasi | Laminar convective heat transfer of $Al_2O_3$/water nanofluid through square cross-sectional duct | 2013 | 111 |
| 13 | MA Ansari, HM khan, MA Alzohairy, M Jalal, SG Ali, R Pal, J Musarrat | Green synthesis of $Al_2O_3$ nanoparticles and their bactericidal potential against clinical isolates of multi-drug resistant *Pseudomonas aeruginosa* | 2015 | 109 |
| 14 | D Yohan, BD Chithrani | Applications of nanoparticles in nanomedicine | 2014 | 101 |
| 15 | S Parham, DHB Wicaksono, S Bagherbaigi, SL Lee, H Nur | Antimicrobial treatment of different metal oxide nanoparticles: a critical review | 2016 | 97 |
| 16 | J Sengupta, S Ghosh, P Datta, A Gomes, A Gomes | Physiologically important metal nanoparticles and their toxicity | 2014 | 93 |

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| 17 | ZU Abideen, JH Kim, JH Lee, JY Kim, A Mirzaei, HW Kim, SS Kim | Electrospun metal oxide composite nanofibers gas sensors: A review | 2017 | 91 |
| 18 | SV Rao, GK Podagatlapalli, S Hamad | Ultrafast laser ablation in liquids for nanomaterials and applications | 2014 | 88 |
| 19 | CJ DeSantis, RG Weiner, A Radmilovic, MM Bower, SE Skrabalak | Seeding bimetallic nanostructures as a new class of plasmonic colloids | 2013 | 88 |
| 20 | D Bruggermann | Nanoporous aluminium oxide membranes as cell interfaces | 2013 | 86 |
| 21 | F Kundie, CH Azhari, A Muchtar, ZA Ahmad | Effects of filler size on the mechanical properties of polymer-filled dental composites: A review of recent developments | 2018 | 86 |
| 22 | C Bai, M Tang | Toxicological study of metal and metal oxide nanoparticles in zebrafish | 2020 | 82 |
| 23 | F Parnia, J Yazdani, V Javaherzadeh, SM Dizaj | Overview of nanoparticle coating of dental implants for enhanced osseointegration and antimicrobial purposes | 2017 | 78 |
| 24 | R Liu, R Lal | Nanoenhanced materials for reclamation of mine lands and other degraded soils: a review | 2012 | 78 |
| 25 | E Demir, D Burgucu, F Turna, S Aksakal, B Kaya | Determination of $TiO_2$, $ZrO_2$, and $Al_2O_3$ nanoparticles on genotoxic responses in human peripheral blood lymphocytes and cultured embyronic kidney cells | 2013 | 71 |
| 26 | W Najahi-Missaoui, RD Arnold, BS Cummings | Safe nanoparticles: Are we there yet? | 2020 | 71 |
| 27 | S Neethirajan, MA Clond, A Vogt | Medical biofilms—nanotechnology approaches | 2014 | 68 |
| 28 | K Zhou, X Zhou, J Liu, Z Huang | Application of magnetic nanoparticles in petroleum industry: A review | 2020 | 67 |
| 29 | SD Almeida-Didry, MM Nomel, C Autret, C Honstettre, A Lucas, F Pacreau, F Gervais | Control of grain boundary in alumina doped CCTO showing colossal permittivity by core-shell approach | 2018 | 66 |
| 30 | JC Wang, H Dommati, SJ Hsieh | Review of additive manufacturing methods for high-performance ceramic materials | 2019 | 65 |
| 31 | AK Hussein, A Walunj, L Kolsi | Applications of nanotechnology to enhance the performance of the direct absorption solar collectors | 2016 | 64 |
| 32 | KC Wickramasinghe, H Sasahara, EA Rahim, GIP Perera | Green Metalworking Fluids for sustainable machining applications: A review | 2020 | 64 |

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| 33 | N Biswas, UK Sarkar, AJ Chamkha, NK Manna | Magneto-hydrodynamic thermal convection of Cu–$Al_2O_3$/water hybrid nanofluid saturated with porous media subjected to half-sinusoidal nonuniform heating | 2021 | 63 |
| 34 | H Zhang, Z Li, BN Kim, K Morita, H Yoshida, K Hiraga, Y Sakka | Effect of alumina dopant on transparency of tetragonal zirconia | 2012 | 63 |
| 35 | M Sheikholeslasi, H Sajjadi, AA Delouei, M Atashafrooz, Z Li | Magnetic force and radiation influences on nanofluid transportation through a permeable media considering $Al_2O_3$ nanoparticles | 2019 | 62 |
| 36 | M Daroonparvar, MAM Yajid, NM Yusof, HR Bakhsheshi-Rad | Preparation and corrosion resistance of a nanocomposite plasma electrolyte oxidation coating on Mg-1%Va alloy formed in akuminate electrolyte containing titania nano-adictives | 2016 | 59 |
| 37 | MK Meybodi, A daryasafar, MM Koochi, J Moghadasi, RB Meybodu, AK Ghahfarokhi | A novel correlation approach for viscosity prediction of water based nanofluids of $Al_2O_3$, $TiO_2$, $SiO_2$, and Cu | 2016 | 58 |
| 38 | HA Derazkola, A Simchi | Effects of alumina nanoparticles on the microstructure, strength and wear resistance of poly (methyl methacrylate)-based nanocomposites prepared by friction stir processing | 2018 | 58 |
| 39 | AK Mishra, BB Lahiri, J Philip | Thermal conductivity enhancement in organic phase change material (phenol-water system) upon addition of $Al_2O_3$, $SiO_2$, and $TiO_2$ nano-inclusions | 2018 | 52 |
| 40 | B Mukherjee, OA Rahman, A Islam, M Sribalaji, AK Keshri | Plasma sprayed carbon nanotube and graphene nanoplatelets reinforced alumina hybrid composite coating with outstanding toughness | 2017 | 50 |
| 41 | JA Ali, AM Kalhury, AN Sabir, RN Ahmed, NH Ali, AD Abdullah | A state-of-the-art review of the application of nanotechnology in the oil and gas industry with a focus on drilling engineering | 2020 | 50 |
| 42 | KH Huynh, XH Pham, J Kim, SH Lee, H Chang, WY Rho, BH Jun | Synthesis, properties, and biological applications of metallic alloy nanoparticles | 2020 | 49 |
| 43 | S Nagappan, SS Park, CS Ha | Recent advances in superhydrophobic nanomaterials and nanoscale systems | 2014 | 49 |
| 44 | EJ Park, GH Lee, C Yoon, U Jeong, Y Kim, MH Cho, DW Kim | Biodistribution and toxicity of spherical aluminum oxide nanoparticles | 2016 | 48 |
| 45 | M Hasan, J Zhao, Z Jiang | Micromanufacturing of composite materials: a review | 2019 | 48 |

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| 46 | I Nowrouzi, AK Manshad, AH Mohammadi | Effects of $TiO_2$, MgO, and γ-$Al_2O_3$ nanoparticles in carbonated water on water-oil interfacial tension (IFT) reduction in chemical enhanced oil recovery (CEOR) process | 2019 | 46 |
| 47 | V Karagkiozaki, S Logothetidis, AM Pappa | Nanomedicine for atherosclerosis: molecular imaging and treatment | 2015 | 45 |
| 48 | VK Sharma, V Kumar, RS Joshi | Investigation of rare earth particulate on tribological and mechanical properties of Al-6061 alloy composites for aerospace application | 2019 | 45 |
| 49 | M Arshadi, F Mousavinia, A Khalafi-Nezhad, H Firouzabadi, A Abbaspourrad | Adsorption of mercury ions from wastewater by a hyperbranched and multi-functionalized dendrimer modified mixed-oxides nanoparticles | 2017 | 43 |
| 50 | R Chakravarty, A Dash | Role of nanoporous materials in radiochemical separations for biomedical applications | 2013 | 41 |

*3.2. Research developments in the fiels of $Al_2O_3$ nanoparticle in biomedical application*

From the data that we obtained using Publish or Perish, it is known that there are 987 articles published and indexed by Google Scholar with the keywords "$Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, biomedical application" from 2012–2022. The trend of research developments on aluminium oxide nanoparticles in biomedical applications is shown in **Figure 1.**

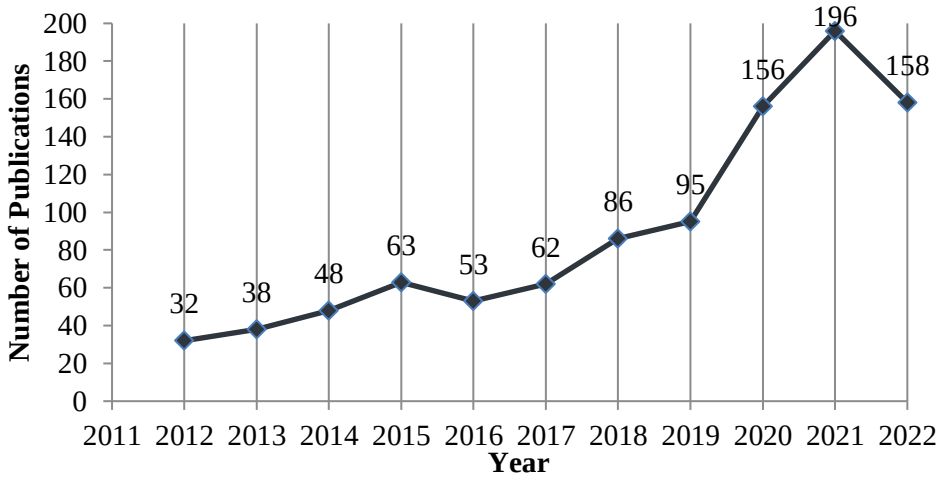


**Figure 1.** Research trend in aluminium oxide in biomedical application

Figure 1. shows that research related to biomedical applications on $Al_2O_3$ nanoparticles is increased in 2012 by 32 articles to 63 articles in 2015. However, in 2016 the articles were decreased to 53 articles and increased again in 2017 to 2021. The research on this topic decreased again in 2022, from 196 publications in 2021 to 158 in 2022. The highest number of articles was in 2021 with 196 articles and the lowest was in 2012, which was 32 articles.

*3.3. Visualization $Al_2O_3$ nanoparticle in biomedical application topic area using VOSviewer*

Based on the mapping of various research results through the search for $Al_2O_3$ nanoparticles in biomedical applications, they are divided into 8 clusters, namely:

i. Cluster 1 has 70 items, there are agglomeration, $Al_2O_3$ nanoparticle, amount, analysis, base fluid, bio medical application, biomedical engineering, biomedical study, biomedical science, characteristic, comparative study, conductivity, convective heat transfer coolant, copper, copper oxide, Cu nanoparticle, CuO, diameter, dispersion, drug, effect, electronic, engineering, enhancement, ethylene glycol, field, flow, fluid, heat transfer, heat transfer application, heat transfer enhancement, hybrid nanofluid, hybrid nanofluid flow, hybrid nanoparticle, impact, increase, magnetic field, magnetic nanoparticle, mechanical, metallic nanoparticle, mixed convection, mixture, nano fluid, nano particle, numerical simulation, performance, porous medium, presence, radiation, sheet, silver, stability, suspension, system, temperature, thermal conductivity, thermal radiation, titanium dioxide, type, variation, viscosity, volume fraction, water, water nanofluid, and wide range.
ii. Cluster 2 has 51 items, there are adsorbent, adsorption, alloy, aluminium, antibacterial activity, atomic layer deposition, attention, biomedical application, ceramic, characterization, coating, comparison, corrosion behavior, decomposition, deposition, development, energy, evaluation, fabrication, formation, graphene, green synthesis, growth, iron oxide nanoparticle, metal, metal nanoparticle, metal oxide nanoparticle, nano Al, nanopowder, nanostructure, optimization, oxidation, phase, plasma, potential biomedical application, powder, preparation, process, removal, sample, sensor, solution, state, structure, study, surface, surface modification, synthesis, technique, thin film, and ZnO nanoparticle.
iii. Cluster 3 has 45 items, there are adverse effect, $Al_2O_3$, $Al_2O_3$ np, alumina, aluminium oxide, aluminium oxide nanoparticle, aluminium, aluminium oxide, biomedical field, CaO, catalysis, catalyst, $CeO_2$, cerium oxide, drug delivery, figure, improvement, iron, magnesium oxide, medical application, metal oxide, MgO, nanofluids, oxide, oxide nanoparticle, oxygen, potential application, SiC, silica, silicon, silicon carbide, SiO, $SiO_2$, $TiO_2$, titanium oxide, treatment, utilization, variety, zinc oxide, zinc oxide nanoparticle, zirconium oxide, ZnO, ZrO, and $ZrO_2$.
iv. Cluster 4 has 39 items, there are addition, aerospace, aluminum nanoparticle, behavior, biocompatibility, composite, corrosion resistance, density, environment, experimental investigation, flexural strength, form, friction, hardness, incorporation, industrial application, industry, influence, investigation, layer, matrix, mechanical property, microstructure, particle, present study, property, reinforcement, role, shape, size, strength, superior property, TiO, $TiO_2$ nanoparticle, titanium, wear resistance, zirconia, and zirconium.
v. Cluster 5 has 36 items, there are adhesion, alumina nanoparticle, aluminum alloy, aluminum oxide np, application, carbon, carbon nanotube, cell, challenge, chemical, combination, comprehensive review, cytotoxicity, drug delivery system, example, food, gold nanoparticle, hydrogel, interest, membrane, nano, nanocomposite, nanomaterial, novel, overview, poly, polymer, production, recent advance, recent progress, research, review, silicon dioxide, toxicity, use, and wastewater treatment.
vi. Cluster 6 has 17 items, there are Ag nanoparticle, AgNP, biomedical use, composition, $Fe_2O_3$, $Fe_3O_4$, gene, interaction, iron oxide, magnesium, modification, nanoparticles, pva, recent development, silver nanoparticle, titanium alloy, and way.
vii. Cluster 7 has 11 items, there are additive, aluminum oxide nanoparticle, basis, bulk, concentration, efficiency, minimum quantity lubricant, nanomedicine, oil, steel, and vegetable oil.
viii. Cluster 8 has 3 item, there are area, nanotechnology, and science.

The eigth clusters are marked with different colors, red for cluster 1, green for cluster 2, dark blue for cluster 3, yellow for cluster 4, purple for cluster 5, light blue for cluster 6, orange for cluster 7, and brown for cluster 8. The relationship between one topic and another is shown in Figure 2. for network visualization, Figure 3. for overlay visualization, and Figure 4. for density visualization.

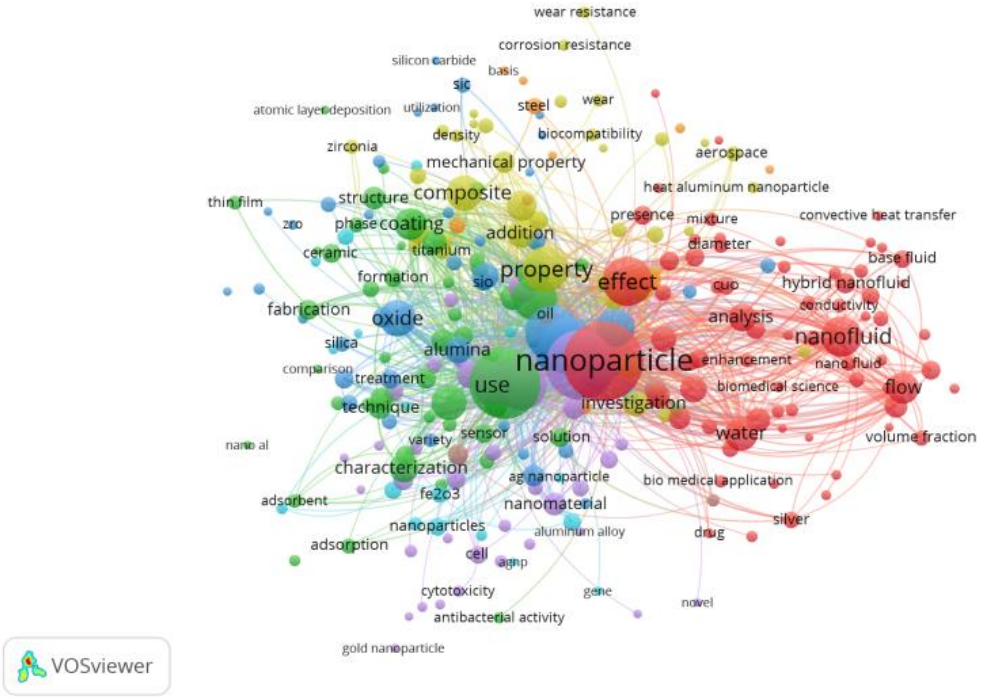


**Figure 2.** Network visualization for $Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, and biomedical keywords

Figure 2. shows the relationship between the topics found in the cluster is illustrated with a line connecting each topic to another [9]. In the network visualization found in Figure 2., different colors indicate which cluster the topic belongs to [18]. From Figure 2. for $Al_2O_3$ nanoparticle items, found in cluster 1 with 101 links and 22 occurrences, for aluminum oxide nanoparticles, found in cluster 3 with 60 links and 16 occurrences, and for biomedical application items found in cluster 2 with 252 links and 313 occurrences.

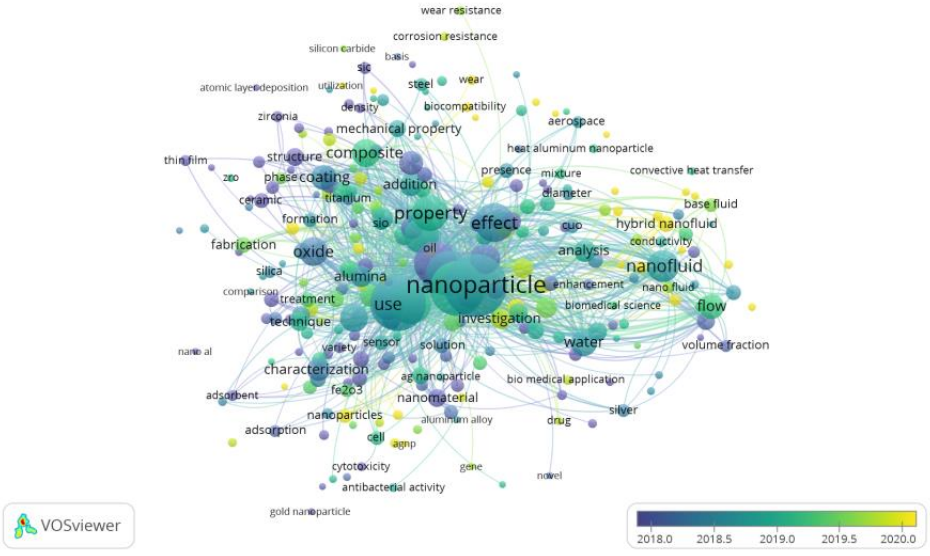


**Figure 3.** Overlay visualization for $Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, and biomedical application keywords

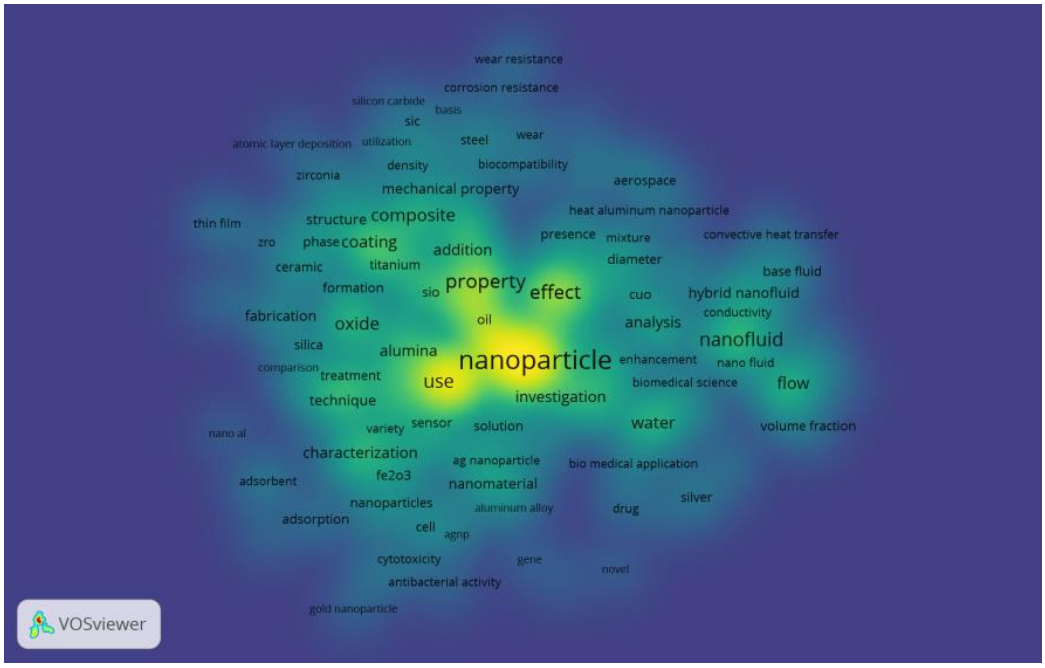


**Figure 4.** Density visualization for $Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, and biomedical application keywords

Furthermore, overlay visualization in Figure 3. shows that research on $Al_2O_3$ nanoparticles in biomedical applications is mostly carried out in 2018 to 2020. Density visualization is depicted in Figure 4. In density visualization, there are points that depends on item density. Thus, this picture shows that the larger the circle, the denser or more frequent the keywords in question appear [17].

## 4. Conclusion

In this analysis, bibliometrics is used to determine research trends regarding $Al_2O_3$ nanoparticles in biomedical applications from 2012 to 2022. This research data was obtained through the Publish or Perish application and visualized using VOSviewer software. The keywords used in this bibliometric analysis are $Al_2O_3$ nanoparticle, aluminium oxide nanoparticle, and biomedical application. From this analysis, there were 987 articles that matched with the keywords and the research trends that tended to increase even though there was a slight decline in 2016. From these articles, 8 clusters with various topics were found and the year with the most articles was in 2021, which was 196 articles.

## References

[1] A. Albanese, P. S. Tang, and W. C. W. Chan, "The effect of nanoparticle size, shape, and surface chemistry on biological systems," *Annu. Rev. Biomed. Eng.*, vol. 14, pp. 1–16, 2012.

[2] A. Prakash, S. Satsangi, S. Mittal, B. Nigam, P. K. Mahto, and B. P. Swain, "Investigation on Al2O3 nanoparticles for nanofluid applications-a review," *IOP Conf. Ser. Materails Sci. Eng.*, vol. 377, pp. 1–7, 2018.

[3] P. Hassanpour *et al.*, "Biomedical applications of aluminium oxide nanoparticles," *Micro Nano Lett.*, vol. 13, no. 9, pp. 1227–1231, 2018.

[4] A. Mukherjee, M. Sadiq, T. C. Prathna, and N. Chandrasekaran, "Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications," *FORMATEX*, pp. 245–251, 2011.

[5] A. Z. Ziva, Y. K. Suryana, Y. S. Kurniadianti, A. Bayu, D. Nandiyanto, and T. Kurniawan, "Mechanical engineering for society and industry recent progress on the production of aluminum oxide (Al2O3) nanoparticles : A review," *Mech. Eng. Soc. Ind.*, vol. 1, no. 2, pp. 54–77, 2021.

[6] A. Nazari, S. Riahi, S. Riahi, S. F. Shamekhi, and A. Khademno, "Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete," *J. Am. Sci.*, vol. 6, no. 5, pp. 2–6, 2014.
[7] A. F. Prakash, G. J. D. Babu, M. Lavanya, K. S. Vidhya, and T. Devasena, "Toxicity studies of aluminium oxide nanoparticles in cell lines," *Int. J. Nanotechnol. Appl.*, vol. 5, no. 2, pp. 99–107, 2011.
[8] S. Ghotekar, "Plant extract mediated biosynthesis of Al2O3 nanoparticles- a review on plant parts involved, characterization and applications," *Nanochem Res*, vol. 4, no. 2, pp. 163–169, 2019.
[9] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer," *J. Eng. Sci. Technol.*, vol. 17, no. 2, pp. 1135–1149, 2022.
[10] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. Marc, "How to conduct a bibliometric analysis : An overview and guidelines," *J. Bus. Res.*, vol. 133, pp. 285–296, 2021.
[11] S. A. Ebrahim, A. Ashtari, M. Z. Pedram, and N. A. Ebrahim, "Publication trends in drug delivery and magnetic nanoparticles," *Nanoscale Res. Lett.*, vol. 14, no. 164, pp. 1–14, 2019.
[12] M. Darroudi, M. Gholami, M. Rezayi, and M. Khazaei, "An overview and bibliometric analysis on the colorectal cancer therapy by magnetic functionalized nanoparticles for the responsive and targeted drug delivery," *J. Nanobiotechnology*, vol. 19, no. 1, pp. 1–20, 2021.
[13] Y. Liu, S. Zhu, Z. Gu, and Y. Zhao, "A bibliometric analysis: Research progress and prospects on transition metal dichalcogenides in the biomedical field," *Chinese Chem. Lett.*, vol. 32, no. 12, pp. 3762–3770, 2021.
[14] N. Ranjan, "Chitosan with PVC polymer for biomedical applications: A bibliometric analysis," in *Materials Today: Proceedings*, 2022.
[15] A. Naganthran *et al.*, "Synthesis, characterization and biomedical applications of silver nanoparticles," *Materials (Basel).*, vol. 15, no. 427, pp. 1–43, 2021.
[16] Y. Tang, H. Xin, F. Yang, and X. Long, "A historical review and bibliometric analysis of nanoparticles toxicity on algae," *J. Nanoparticle Res.*, vol. 20, no. 4, 2018.
[17] Tupan, "Perkembangan bibliometrik dengan VOSviewer terhadap perkembangan hasil penelitian bidang pertanian di Indonesia," *VISI PUSTAKA*, vol. 18, no. 3, pp. 217–230, 2016.
[18] N. J. Eck and L. Waltman, "Citation-based clustering of publications using CitNetExplorer and VOSviewer," *Scientometrics*, vol. 111, no. 2, pp. 1053–1070, 2017.