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Research paper

# Review of nanotechnology value chain for water treatment applications in Mexico

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**Abstract**

Nanotechnologies are part of a new industrial platform with the capability to surpass existing tech-intensive systems for water treatment. Accordingly, many countries apply nanotechnology-based processes to solve problems associated with water. The authors of this article review the state of nanotech applications for water treatment in Mexico. To this purpose, they follow the trajectory of the nanotech package; from research and development to its commercialization. The study encompassed several stages: a bibliometric analysis (publications), a database with all the research groups looking at this issue, a catalog of all related patents and, finally, an overview of Mexican nano-companies in the water sector.


*Keywords:* Nanotechnologies; Water treatment; Value chain; Water deprivation

## 1. Introduction

Water-related problems are a persistent global issue. Various factors, such as population growth, urbanization, and industrialization (associated with an increase in production and consumption), have continually stressed hydrological resources [1]. The increasing use of fertilizers and chemical materials is another factor that has contributed to the eutrophication of rivers and the generation of dead zones in different habitats [2]. The mismanagement of wastewater as well as the lack of public policies complicated the scenario [3]. It is, therefore, a complex and multidimensional problem. Faced with this situation, researchers developed new technologies to ease the pressure on this limited natural resource.

Mexico is the eleventh largest economy in the world and an emerging industrial power. Water, for both economic and social reasons, is an important yet scarce resource despite making up about 71% of the earth's surface. The need to find effective solutions to control the contamination of water for industrial, agricultural and household activities is a key issue for the country's development. Despite being a matter of concern, water scarcity and pollution have not been successfully addressed by the Mexican government.

According to the National Water Commission (CONAGUA), 7 of the 13 hydrological-administrative regions in which the national territory is divided suffer a high degree of water stress. The one that corresponds to the Valley of Mexico, where a great part of the industrial activity of the country concentrates, experiences very high stress.[1] A significant imbalance exists between the average natural availability and the demand for potable water. 77% of the national population is concentrated in regions where only 31% of viable water sources are available for use. This is supported by data from the Water Advisory Council, which asserts that 2/3 of our territory is considered arid or semi-arid, and almost 80% of the country's

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[1] Cfr. http://recsa.mx/reportes_recsa/reportes/Reporte2.pdf.

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population is concentrated within that territory.[2] In the medium- and long-term, the cost of providing drinking water to citizens, industry and the countryside will increase significantly. CONAGUA estimates show that there is an overexploitation of the underground reserves that currently supply more than 28% of the demand. In the Valley of Mexico an increase of 2.6 million inhabitants is expected by the year 2030 [4].

This is an opportunity awaiting resolution. Nanotechnologies (NTs) are portrayed as the solution to many problems, among them, water scarcity and pollution. The technological power of NTs occurs at the nanoscale ($1 \times 10^{-9}$), where nanomaterials behave differently from their bulkier counterparts. At the nanoscale, different physicochemical properties are exhibited, which makes them suitable for several applications involving water, including desalination, purification and remediation. Nanomaterials could provide solutions to adsorption, catalysis, disinfection and water cleaning [5].

There is a considerable lacuna in the academic literature about what is being done in the country regarding research and development (R&D), commercialization and consumption of nano applications for water. Our aim is to fill that void with actual data. The information would be of interest to government officials, researchers, students, and other agents, such as non-governmental organizations (NGOs), companies, decision-makers and other actors. To that end, we study the nanotech value chain to identify relevant areas where NTs may contribute to solutions.

In order to fulfill the objectives of the project, we had to overcome several challenges. The most important was the dispersion of data. Mexico lacks a national strategy in nanotechnology, specific public policy or an institution in charge of following nanotech developments, especially in terms of commercialization. Having basic data on any given issue is central to the design and implementation of a specific policy. We therefore decided to tackle the lack of information related to nano applications for water in Mexico.

## 2. Nanotech development in Mexico

According to prior studies based on bibliometric research, which contemplates patents, companies, human resources and infrastructure, Mexico ranks second in Latin America, after Brazil, in the development of NTs [6–8]. Nevertheless, there are no data related to R&D, commercialization and consumption of nano-applications for water. There is some information drawn from isolated initiatives that provide a panorama of what is happening with NTs in this country. For instance, the Ministry of the Economy, in partnership with the Center for Advanced Materials Research (CIMAV), carried out an extensive study on NTs in Mexico [9], and illustrated that between 1998 and 2004 the Mexican government, through the National Council of Science and Technology (CONACyT), supported a total of 152 research projects worth $14.4-million. Takeuchi and Mora [10] added to this amount and estimated the total funds for nano R&D (between 2006 and 2009) at roughly $60-million. There are a series of agreements between Mexican institutions and research centers with international organizations to cope with the lack of funding. That strategy generated investments of up to $60-million [9].[3]

As a subsection of the National Development Plan for 2007–2012, the National Expenditure on Science and Technology and Innovation (GNCTI) was inaugurated. The aim of the GNCTI was to endorse the development of new knowledge, including nanotechnology [11]. CONACyT reported that the number of projects with funding grew by 5% in the last 5 years, with the greatest increase (6.9%) in the 2013–2014 period. The GIDE/GDP ratio in 2014 ranked Mexico above the Latin American average (0.54% versus 0.29%); only below Brazil and Argentina (1.21% and 0.58%, respectively), but much lower than the OECD average (2.37%) [12].[4]

As a reflection of the economic inequalities, research is highly concentrated in Mexico. Almost 90% of the GNCTI is concentrated in four institutions: the National Autonomous University of Mexico (UNAM) (52.9%), the Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV) (13%), the National Polytechnic Institute (IPN) (10.1%) and the Metropolitan Autonomous University (UAM) (9.8%).[5] In general terms, nanotechnology development in Mexico has been concentrated into three areas of interest: creating research networks, national laboratories and industrial clusters [13]. Yet there is little information regarding specific areas of application for NTs and very scarce information on water applications. Therefore, we implemented a methodology to try to uncover as much information as possible from the nanotech water value chain in the country.

## 3. Methodology

Our data were concentrated in three areas of application (according to the final use of the water): remediation and purification; detection and filtration, and desalinization. We decided to employ these categories after reviewing specialized literature on the matter [14–18]. We acknowledge that all those procedures are implemented, sometimes simultaneously or in combination, but the classification was created to detect the potential use of the water and not the technique (procedure) in

[2] Cfr. http://www.aguas.org.mx/sitio/index.php/panorama-del-agua/agua-en-mexico.

[3] For example, the Cluster of Innovation in Nanotechnology in North America was created under an agreement between the University of Arizona, CIMAV and CONACyT [21].

[4] It should be noted that this report considered the reformulation of the Frascati Handbook, through the Organization for Economic Cooperation and Development (OECD): "*Research and experimental development (R & D) comprise creative and systematic work undertaken in order to increase the stock of Knowledge – including knowledge on humankind, culture and society – and to devise new applications of available knowledge*" (p. 44) [12].

[5] For further details, see the statistics provided annually by CONACyT's Integrated Information System on Scientific Research, Technological Development and Information (SIICYT), at: http://www.siicyt.gob.mx/index.php/estadisticas/indicadores.

Table 1
Topics and keywords used for data searches on nanotechnology in water issues.

| Application | Keywords |
| --- | --- |
| Remediation and purification | ((“water treat*”or “water-treat” or “wastewater” or “waste water” or “waste-water” or “disinfection” or “pollutant” or “pollution” or “groundwater” or “ground-water” or “water-remed*” or “water contamina*”or “contaminated water” or “treated wastewater” or “ treating wastewater” or “water-remed*” or “industrial water” or “water disinfect*” or “water-disinfect*” or “ pesticide remov*”or “residual” or “pesticide remediat*” or “purifica*” or “freshwater” or “natural” or “potab*” or “sterili*”) and water and nano*) |
| Detection and filtration | ((“membrane filtration” or “dendrimer filtering” or “filtration” or “nanofiltration” or “nano-filtration” or “membrane system” or “reverse osmosis” or “electrodialysis” or “multiple stage flash distillation” or “activated carbon” or “drink*”) and water and nano*) |
| Desalinization | ((“nanoporous polymeric materials”) or (“brackish” or “desalination” or “saltwater” or “salt water” or “salt-water” or “seawater” or “sea water” or “sea-water”) and nano*) |

itself.[6] At the end of each search protocol, we filtered the results with the nano* operator. With the caveat that the procedure omits other results, the research nonetheless provides a landscape of what is being conducted in Mexico regarding nano and water. The data were consistent with findings in other areas of research [13,19].

To obtain information about nanotech/water R&D in Mexico, we use three search strategies. The first strategy involved identifying who performs scientific research on NT applications for water in the country. This stage required a bibliometric analysis and a social network modeling of data. The search engine employed was the Web of Science (WoS). In the Topic Subject (TS) section we analyzed the title, the abstract, and the keywords of both the author and the indexer. We looked for research papers with at least one author attached to a Mexican institution over a period of fifteen years (2000–2015). The keywords are described in Table 1. Next, we filtered the results according to the three categories of nanotechnology applications in water: remediation and purification, detection and filtration and desalination.

Next, we grouped all of the academic bodies (CAs) of the Professional Development Program for Teachers (PRODEP) of the Ministry of Public Education (SEP) that foster research areas associated with nanotechnology and water. This was the second strategy for R&D. The CAs from PRODEP constitutes a program that endorses the formation of research clusters around specific subjects. This program is, basically, a catalog of researchers that are affiliated in public institutions of higher education in Mexico. We used the search engine within the PRODEP website to identify all of the CAs looking at nanotechnology and water (http://promep.sep.gob.mx/ca1/). There are several institutions affiliated with the PRODEP program, such as State Public Universities, Polytechnic Universities, Technological Universities, Federal Technological Institutes, Decentralized Technological Institutes, Polytechnics and Normal Schools.[7] This search strategy has been employed in other research processes and for other topics, which provided a simplified process for the collection of data [13]. Table 2 illustrates the filters (key words) employed to process all data.

As a third strategy, we performed a manual search across related websites. The institutions included in this procedure are not part of the CA program of PRODEP. The list of institutions comprises UNAM, IPN, UAM, all the research centers of CONACyT and other private institutions.[8] The data obtained were registered in a database that includes the following fields: name of the institution, names of the researchers, research area of interest (nano & water) and email address.

In order to seek a deeper understanding of the potential societal benefits of nano-water development in Mexico, we explored the number of patent applications registered with the World Intellectual Property Organization (WIPO). It is worth mentioning that there are no precise methods to determine the social impact of a technological breakthrough like NTs. This has opened spaces to evaluate NTs not only for their scientific value, but also their influence on policy-making, socio-environmental affairs and societal benefits [30]. Generally, the initial stage to bring any given technology to society is through the patent system. We acknowledge that the mechanism may be subjected to distortions such as monopolies, political and economic schemes, social pressures, junctures, among other issues; nevertheless, the prospective studies regarding societal benefits of new technologies are scarce and require systematization [31]. In this order of ideas, Normann (2012) explains: “*the ‘societal benefits’ refers to the contribution of the research to the capital of a nation, stimulating social issues, or in forming public discussion and policy-making*” [32].

After exploring WIPO’s Patentscope database, we classified the information obtained in the same categories (remediation and purification; detection and filtration and desalinization) applied in the bibliometric research effort. It should be noted that the procedure to register applications and patents differs from country to country and legal representative. The results may vary among databases, but WIPO concentrates most on patent registries. Finally, we performed a manual filtering of each registry to eliminate duplicates or records that were not

[6] In treatment and remediation, NTs have the potential to improve the efficiency of water treatment: flocculation, sedimentation, coagulation and activated carbon [20–24]. Some nanoparticles are highly effective in capturing heavy metals, facilitating their removal from water bodies. For filtration, NTs have the potential to develop devices capable of detecting and monitoring water contamination, accelerating the transit for its remediation or purification [16,25,27,29]. For desalination, nano processes promise to decrease costs; for instance, through the use of membranes with nanoparticles of silver and zinc [26,28].

[7] In Mexico, Normal Schools aim to train teachers of the Basic Education System (elementary schools). They are managed by the federal and state governments. The profile of each institution varies according to the regional location, but essentially the curricula remains the same, and this includes: Urban Normal Schools, Rural Normal Schools, Regional Centers of Normal Education and, in more recent years, the Normal Experimental Schools.

[8] The names of some institutions do not have an “official translation” so, in order to avoid confusion, we used the actual Spanish name.

Table 2
Search method for filtering Academic Bodies data from PRODEP.

| 1st filter<br>Subsystem | 2nd filter<br>Knowledge area | 3rd filter<br>Consolidation degree | 4rd filter<br>Keywords |
|---|---|---|---|
| a) Public Universities and Related<br>b) Polytechnic Universities<br>c) Technological Universities<br>d) Federal Technological Institutes<br>e) Decentralized Technological Institutes<br>f) Normal Schools | a) Agriculture and fishing<br>b) Health<br>c) Natural Sciences and engineering<br>d) Social and administrative<br>e) Engineering and Technology<br>f) Education, humanities and arts | Training Academic Bodies (CAEF)<br>In consolidation, Academic Bodies (CAEC)<br>Consolidated Academic Bodies (CAC) | Nanotechnology & and water |

related to the topic. In Table 3 and Fig. 1, we summarize the terms and the steps employed for the data research.

The next stage was the identification of Mexican companies manufacturing nanotechnology products oriented to remediation/purification, detection/filtration or desalination. This was developed from a previous inventory of nanotechnology companies in Mexico [8]. The full database is available at the website *nano-economy in Mexico* [33]. We are aware that the current number of Mexican nanotechnology companies is presently unknown due to the lack of regulation and/or the dynamism of the market. However, this research provides an overview of the economic and productive insertion of NTs in a common sensitive area such as water treatment.

Table 3
Keywords used for patents research on nanotechnology water issues.

| Application | Keywords |
|---|---|
| Remediation and purification | (nano* AND water AND (remediation))<br>(nano* AND water AND (purification)) |
| Detection and filtration | (nano* AND water AND (filtration))<br>(nano* AND water AND(detection)) |
| Desalination | (nano* AND water AND (desalination)) |

## 4. Results and discussion

NTs represent a platform whose technological prowess can make water treatment methods more efficient. In this research, we have followed the path of NTs from R&D to their commercialization in the water sector. This gives us an overview of the area, in addition to its productive insertion and foresight regarding potential societal impact.

The bibliometric analysis delivered 117 research articles for 2000–2015, with at least one author affiliated with a Mexican institution. We classified the articles according to the application area, vis-à-vis remediation and purification, detection and filtration of contaminants and desalination. The results are shown in Fig. 2.

We found only 2% of the articles relating to water desalination used nanotechnological tools. Filtration and detection, on the other hand, represent 36% of the total number of articles. The application area with the most published articles was remediation and purification with 62%. In this area, most research and experimentation made use of carbon nanotubes as well as silver, gold, iron oxide, and magnetite nanomaterials for removing contaminants.

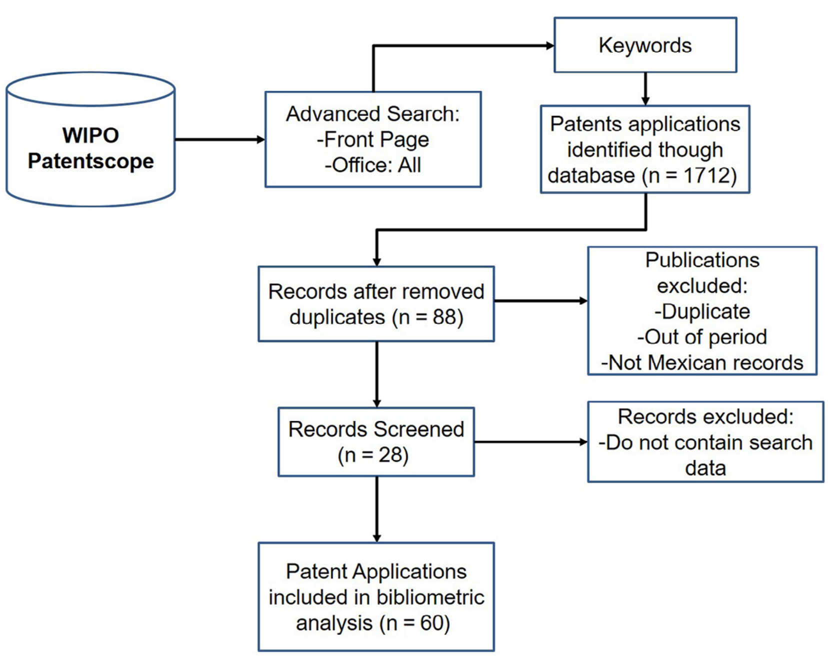


Fig. 1. Nanowater patent research flow diagram.

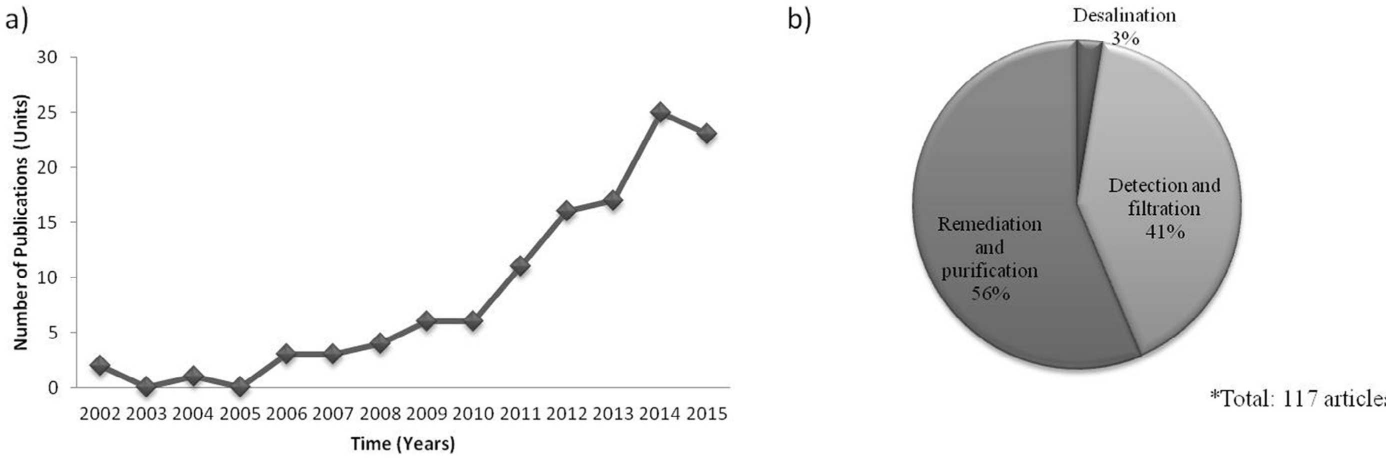


Fig. 2. (a) Nanowater research articles evolution for 2000–2015. (b) Application fields of nanowater articles. Source: Data from Web of Science, up to July, 2016.

Additionally, we performed a collaborative network analysis of the different institutions that publish research articles (using Pajek Software, a program that facilitates visualization and data management). We determined the institutional distribution of nanotechnology water treatment research in Mexico, as well as that of international institutions with collaborative ties.

In Fig. 3, the size of each node is determined by the frequency of participation of each institution, the green nodes represent the foreign institutions, and the red ones represent the Mexican counterparts. Each edge represents the coauthor relationship between institutions. UNAM has the highest number of publications (37), followed by the CIMAV (25), the National

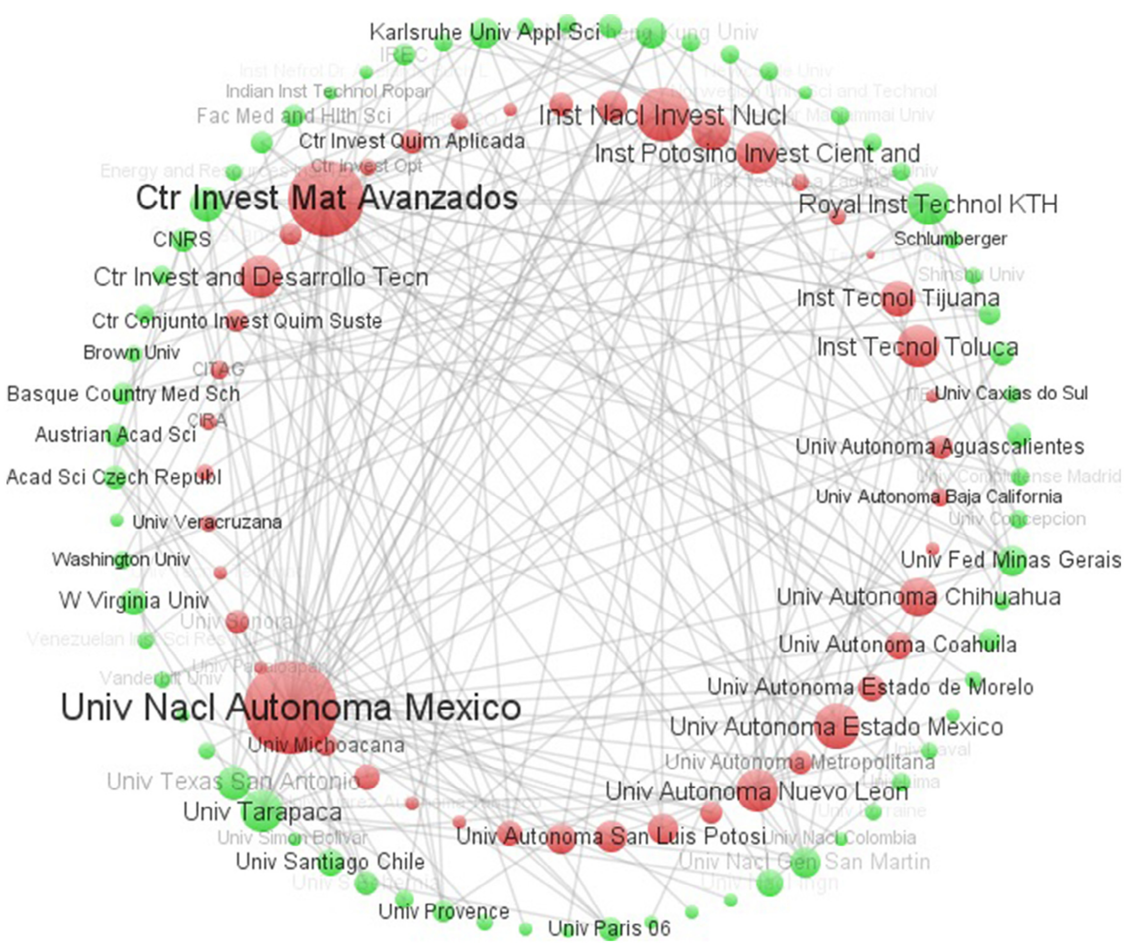


Fig. 3. Institutional network distribution of nanowater treatment research in Mexico. Source: Data from Web of Science, up to July, 2016, elaborated with Pajek Software.

Table 4
Nanowater publications of Mexican institutions by field.

| Institution | Articles |
|---|---|
| a) Remediation and Purification | |
| UNAM | 23 |
| ININ | 9 |
| CIMAV | 9 |
| UAEM | 7 |
| IPN | 7 |
| b) Detection and Filtration | |
| UNAM | 14 |
| IPICyT | 9 |
| CIMAV | 6 |
| Tech. Institute of Toluca | 4 |
| UASLP | 4 |
| c) Desalination | |
| Tech. Institute of Sonora | 1 |
| UAQ | 1 |

Source: Data from Web of Science, up to July, 2016.

Institute of Nuclear Research (ININ) (11) and the Potosino Institute of Scientific and Technological Research (IPICYT) (10).

These numbers are directly related to the financial support that the Mexican government allocates to some central educational institutions in our country, as well as to certain research centers. These institutions also have a more effective diffusion infrastructure than those of medium-scale and/or regional institutes.

In total, we found 45 Mexican institutions with publications in nano water-related areas; however, most had published fewer than three articles within the period of analysis. Therefore, we decided to disclose the top 5 institutions with the highest number of publications for each area of application (Table 4). For desalination, we found two articles; one published by the Technological Institute of Sonora, and another by the Autonomous University of Querétaro (UAQ).

Regarding the main collaboration countries, the United States topped the list with 9 articles; Spain, figure in second place with 8; France on third with 7 and Chile with 6 articles (Fig. 4).

On the other hand, we found 41 CAs conducting research on NTs for water treatment in Mexico, of which 14 are registered in the PRODEP CA program (Table 5).

The other 27 CAs doing research in nano-water applications are distributed across the IPN with 13; UNAM 6; IPICyT 4; the Autonomous University of Yucatan (UADY) 2; the Monterrey Technological Institute of Higher Education (ITESM) 1; and the University of the Americas (UDLA) 1. We illustrate this distribution in Fig. 5.

The IPN and UNAM host almost 46% of the academic bodies. Essentially, most of the research groups (29 out of 41) are related to the analysis of nanostructured materials, their characterization, and possible applications for remediation-purification of water bodies. Additionally, there are 9 CAs and 20 non-CAs developing nanomaterials for water remediation-purification. 20 investigations out of 29 focused on the analysis of nanostructured materials to speed up cleaning methods. None explored side effects, such as the effects upon the environment and human health. On the other hand, 10 out of the 14 CAs performed R&D in the detection-filtration area, which represents 71% of the total research effort of this program. We found only one group looking at desalinization (reverse osmosis centrifuge) in the Faculty of Chemical Engineering at the UADY.

Thirteen research groups have combined research on remediation-purification analysis and experimentation in the

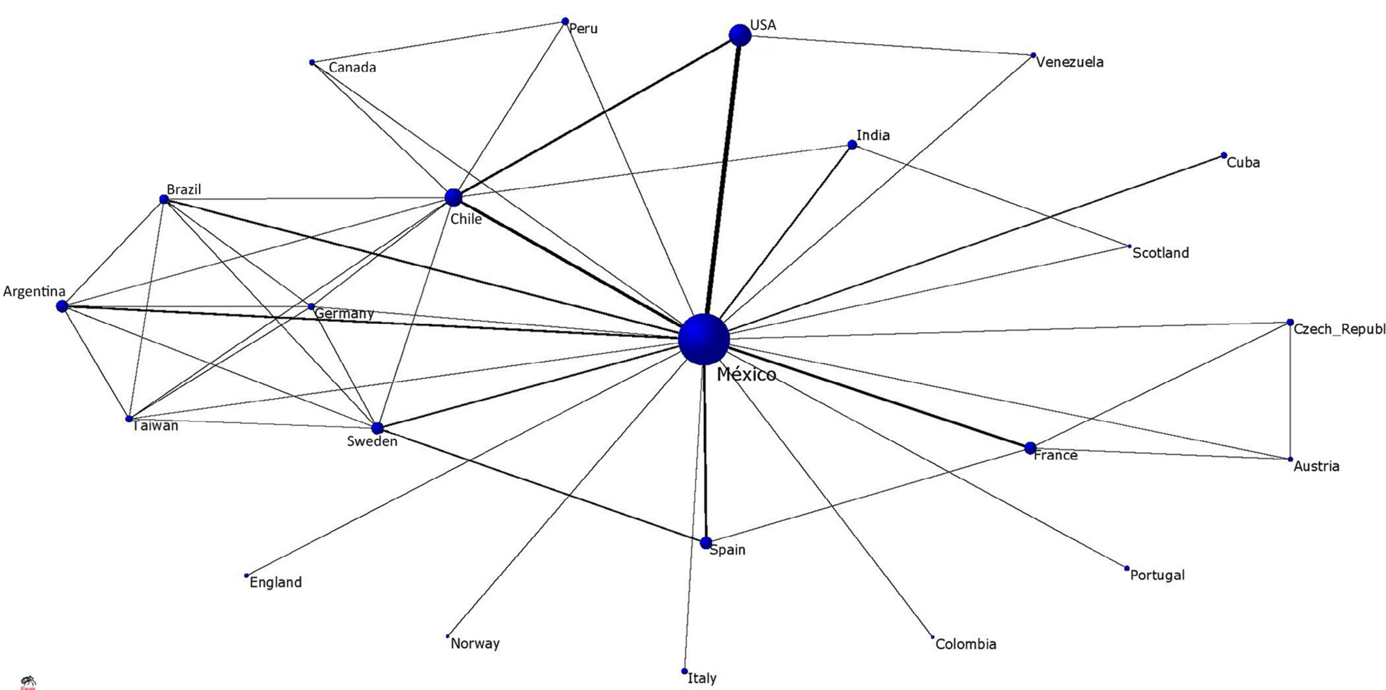


Fig. 4. International nanowater partnership network. Source: Data from Web of Science, up to July, 2016, elaborated with Pajek Software.

Table 5
Nanowater research and development academic bodies.

| Institution | Department | Research Group | Remediation/ Purification | Detection/ Filtration | Desalination |
|---|---|---|---|---|---|
| Technological Institute of Ciudad Madero | Nanotechnologies and Renewable Energy | José Aarón Melo Banda, Adriana Isabel Reyes de la Torre | X | | |
| Technological Institute of Oaxaca | Materials Science and Environmental Chemistry | Alma Dolores Pérez Santiago, María de Jesús Gil Gallegos | | X | |
| Technological Institute of Toluca | Nanotechnology Development and Evaluation of Materials for Environmental Applications | María Sonia Mireya Martínez Gallegos, Genoveva García Rosales, Ma. Guadalupe Macedo Miranda | X | X | |
| Autonomous University of Sinaloa | Crystals and Environmental Engineering | Héctor José Peinado Guevara, José de Jesús Campos Gaxiola, Adriana Cruz Enríquez | | X | |
| Metropolitan Autonomous University Azcapotzalco | Nanotechnology and Environmental Quality | Mirella Gutiérrez Arzaluz, Lidia López Pérez, Violeta Mujica Álvarez, Miguel Torres Rodríguez, Luis Enrique Noreña Franco, Julia Aguilar Pliego, Víctor Daniel Domínguez Soria, Lilia Fernández Sánchez, Virginia González Velez | X | X | |
| University of Guadalajara Ciénega University Center | Nanomaterials Polymers and Catalysts | Arturo Barrera Rodríguez, Jacobo Aguilar Martínez, Víctor Vladimir Amilcar, Reyes Fernández Escamilla, Joel Sanjuan Raygoza, Oscar Jaime Ríos Díaz | X | | |
| Fidel Velazquez Technological University | Nanotechnology | Manuel Medina Mendoza, Enrique Pérez Valdivieso, Víctor Miguel Almazán | | X | |
| Tula-Tepeji Technological University | Engineering and Environmental Systems | Sergio Tejeda Zúñiga, Fausto Tovar León, Sonia Hernández González, Víctor Alfredo Nolasco Arizmendi, Aurea Guadalupe Gómez Vega | X | X | |
| Celaya Technological Institute | Nanomaterials Chemistry | Juan Carlos Fierro González, Armando Almendarez Camarillo, Gloria María Martínez González | X | | |
| Technological Institute of Morelia Valley | Bioengineering in sustainable agronomy | Guillermo Andrade Espinoza, Abraham García Chávez, Alejandro Romero Bautista, Rebeca González Villegas | X | | |
| Irapuato Higher Technological Institute | Micro- and Nano-sciences | Miguel Ángel Guzmán Altamirano, Javier Gustavo Cabal Velarde | | X | |
| Autonomous University of the State of Morelos | Design and Characterization of New Applicable Materials in Environmental Engineering | Cecilia Cuevas Arteaga, Rosa María Melgoza Aleman, Ma. Guadalupe Valladares Cisneros | | X | |
| Metropolitan Autonomous University Azcapotzalco | Nanostructured Materials Engineering and Applications | Sandra Loera Serna, María Elba Ortiz Romero Vargas, Ana Marisela Maubert Franco, Isaías Hernández Pérez, Marcos May Lozano, Dulce Yolotzin Medina Velázquez | X | X | |
| Metropolitan Autonomous University Lerma | Nanostructured materials | Maricela Arroyo Gómez, Adolfo García Fontes, Ernesto Hernández Zapata, Yuri Reyes Mercado, José Luis Salazar Laureles | X | X | |

filtration-detection of water bodies. In some cases – e.g., CINVESTAV [34] and ITESM [35] – we found clear evidence of such work. In this context, UAM, IPICYT, and CINVESTAV (Monterrey and Mexico City) are part of a set of institutions where R&D has reached higher levels of synergy between areas, as they advance in the characterization of nanomaterials, and then apply it for filtration-detection and remediation-purification. Another interesting fact is that 20 out of the 41 research groups are headquartered in three cities: Jalisco, Monterrey and Mexico City (including its metropolitan area). It is worth noting that these cities are the most-affected by socio-environmental problems, including water scarcity and pollution.

Regarding the patents section, we identified a total of 60 applications for nanotechnology in water treatment: 33 belong to the filtration and detection field; 22 are related to systems or processes for purification or detection; and 5 for water desalinization (Fig. 6).

Of the total patent applications, only 4 belong to Mexican inventors. One was awarded to the Center for Food Research and Development (CIAD); the second to the National Technological Institute of Mexico from the SEP. The remaining two belong to inventors without ties to some public institution. Regarding the area of application, 3 of these patents look into the development of filters for heavy metals and organic matter, and the other to an electro-chemical method of purification.

We note that 56 applications belong to foreign applicants. In descending order, the main countries are the US, UK, France and Japan (Table 6). Concerning companies, Siemens Water Technologies, Pure Water Purification, Degremont and Toray Industries have the largest number of patent applications in the country (Fig. 7).

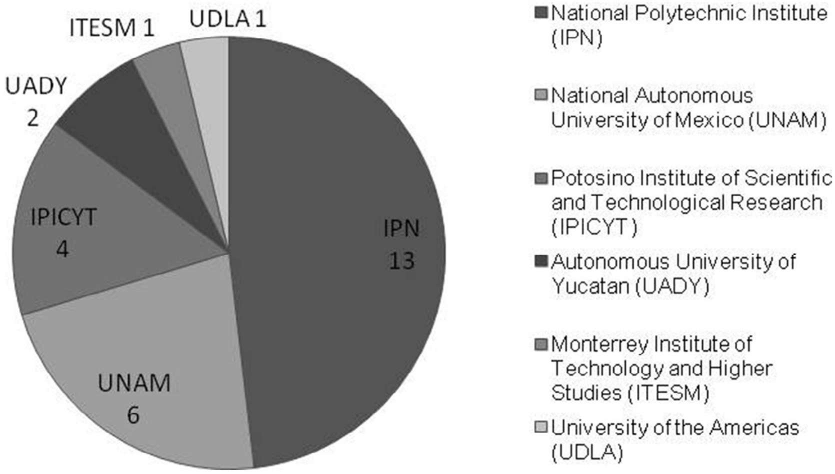


Fig. 5. Institutional distribution of nanowater academic bodies. Source: Data from Web of Science, up to July, 2016.

We identified five companies applying nanotechnology in the functioning of their products. Mexico City and Monterrey have 2, and Guadalajara only 1. These companies are selling products for nanofiltration, and they all have manufacturing facilities in Mexico [36–40].

Environment ACS, located in Mexico City, designs and manufactures tailored nanofiltration systems, which run similar to reverse osmosis platforms [37]. Nanofiltration is an efficient method, for example, to treat water contaminated with pesticides and dye-based, highly toxic chemicals. The equipment used has different configurations: spiral membrane, tubular membrane and hollow fiber membranes. These systems capture wastes, either organic or inorganic, and remove them from water bodies.

Carbotecnia, located in Guadalajara, is a Mexican company that specializes in the development and marketing of activated charcoal for the treatment of household water, in industry and commerce. It offers high-tech equipment for water treatment using different techniques, including nanofiltration [37]. Additionally, the company provides technical advice for equipment and treatment plant installation, and other services.

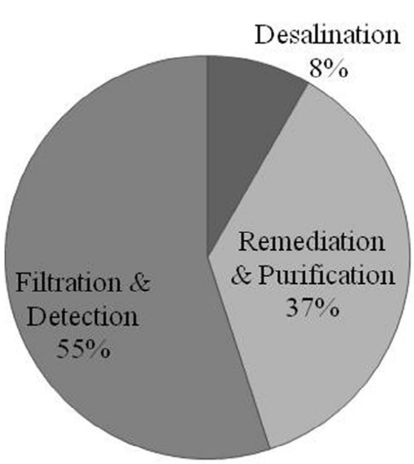


Fig. 6. Nanowater patent application areas. Source: Data from WIPO patentscope database, up to July, 2016.

Global Proventus is located in Monterrey. This company manufactures equipment for water treatment, industrial valves, and pumping equipment. Regarding water treatment, the company offers reverse osmosis, nanofiltration, ultrafiltration, among other products [38]. The company, according to its website, also exports to Europe, America, and Asia.

In Mexico City, we identified Heltec, a company that manufactures water treatment equipment. Its portfolio includes products of ultrafiltration, nanofiltration, microfiltration and electrodeionization [39]. It is unclear whether this company comes from Mexican or foreign capital as its website states that it began operations as a representative of GE Water Technologies. Heltec is a corporation that offers its products in the United States, Canada, Ireland, England, and Germany as well as Central and South America.

The fifth company is Aquapro, whose headquarters are in Monterrey. It offers installation of equipment and water treatment systems, comprehensive advice, in addition to providing supplies to consumers. Concerning nanotechnological applications, Aquapro manufactures nanofiltration equipment. The company uses polyamide membranes in a spiral configuration and applies nanoparticles to remove organic and inorganic contaminants (fouling) [40].

Table 6
Origin countries of patent applicants in Mexico by research area.

| Country | Detection and filtration | Remediation and purification | Desalinization | Total |
|---|---|---|---|---|
| U.S. | 11 | 13 | 1 | 25 |
| U.K. | 3 | 2 | – | 5 |
| Mexico | 3 | 1 | – | 4 |
| France | 3 | – | – | 3 |
| India | 1 | 1 | – | 2 |
| Japan | 1 | – | – | 1 |
| Switzerland | 1 | – | – | 1 |
| South Korea | 1 | – | – | 1 |
| Israel | 1 | – | – | 1 |
| Denmark | 1 | – | – | 1 |
| Canada | – | 1 | – | 1 |
| Germany | – | – | 1 | 1 |

Source: Data from WIPO Patentscope database, up to July, 2016.

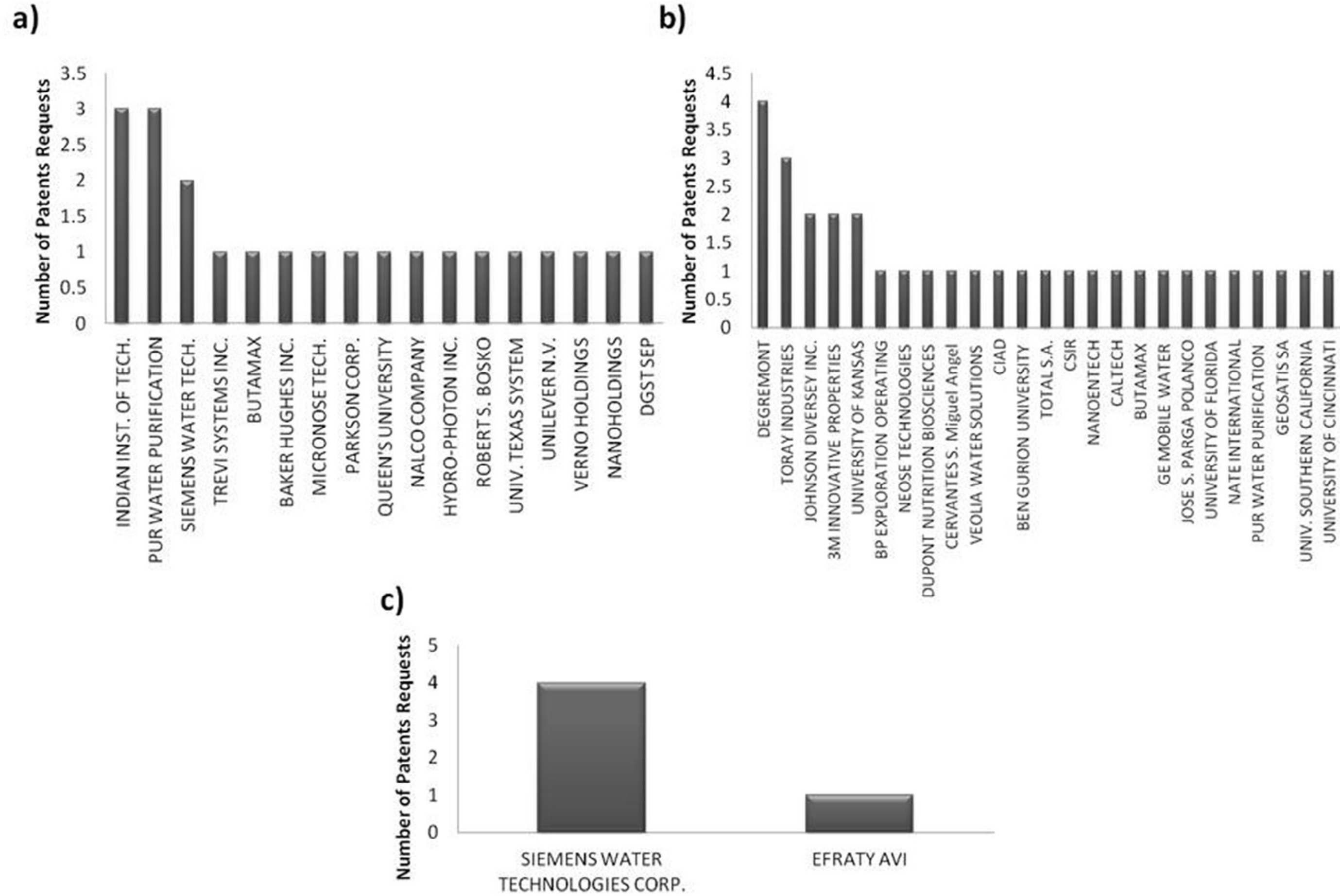


Fig. 7. Patent applicants in Mexico per area: (a) Remediation-Purification, (b) Filtration-Detection; (c) Desalinization. Source: Data from WIPO patentscope database, up to July, 2016.

The results presented here give an overview of the water-oriented nanotechnological applications developed in Mexico. This ranges from scientific research to commercialization of products. The picture denotes certain dynamism, but there is a lack of connection between the various actors involved in their development.

## 5. Conclusions

In addition to increasingly effective public policies, greater responsibility for water body management and awareness of population water use, new scientific developments can contribute to halting the process of water contamination or misuse. Water shortage is alarmingly widespread across an increasing number of countries. NTs are portrayed as an enabling technology package with endless application, of which pollution and water scarcity do not escape the sphere of NT. This article sought to give an overview of the development of NTs in three areas of application in Mexico: filtration and sensing, purification and remediation, and desalination.

We found a considerable amount of scientific research on the subject. There are over 100 articles on nanowater applications and more than 41 institutions sponsoring research lines or groups in the field. However, there is a disassociation between scientific research and the productive sector, and possibly the social sector as well. We located 60 patents in the area, but only four belong to Mexican applicants. The others are owned by foreign and transnational companies. It is noteworthy that the vast majority of nano patents are held by foreign agents, giving the complexity of pollution and water scarcity in the country. This certainly could obscure the potential technological impact of water treatment through nanotechnological means. However, further studies on the subject are required.

A substantial percentage of R&D focuses on institutions in three cities, Guadalajara, Monterrey and Mexico City: urban centers that have significant contamination in their water bodies. The first major challenge of nano R&D is developing cost-efficient and socially driven applications. This involves generating conditions outside of the laboratory to assess their impact on the environment and human health. We noted the absence of long-term studies to assess the accumulation, degradation, and disposal of nanomaterials used in filters, membranes, and devices for water treatment.

In Mexico, the production of devices with these technologies is ongoing. Only five companies are manufacturing nanofiltration devices for water treatment. This, it should be noted, is done in a framework where there is no regulation or legal obligation to label and record nanotech products. This complicates the exercise of having a complete inventory of companies. In this article, however, a general overview on the subject is offered.

In this regard, it can be noted that the average cost of nanofiltration devices is equivalent to five minimum wages, which raises questions about who can buy this type of product; especially in a country where more than half of its population lives in poverty [33,41,42]. The process of the technological transformation in all areas, but especially in social-content sectors such as water treatment, depends on the cost-effectiveness and competitiveness in production at an industrial level. Currently, the high costs, the modest production capacity, the disassociation of scientific research with manufacturing, the lack of monitoring of application development and the absence of planning have limited the link between R&D, production, consumption, and commercialization of NTs for water remediation, treatment, and potabilization in Mexico.

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