# Remediation of Water Contamination in Colombia: Nanotechnology for Water Treatment

**Liliana Dhupelia**
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Especialización en Gestión de la Tecnología y la Innovación (GTI.UPB)

*Remediación para la Contaminación del Agua en Colombia: Nanotecnología para el Tratamiento de Aguas*

*Remediation of Water Contamination in Colombia: Nanotechnology for Water Treatment*

# Participants



| ***Datos del Estudiante (Autor)*** | | | |
|---|---|---|---|
| Name | Liliana Dhupelia | | |
| e-mail | Elle3636@hotmail.com | | |
| Identity | 31412697 | ID UPB | 000292968 |

| Director's Information | |
|---|---|
| Name | Dr. Vladimir Martínez-Tejada |
| e-mail | hader.martinez@upb.edu.co |
| ID kosmos(ID) | |
| Faculty/Institution/Company | Faculty of Mechanical Engineering - UPB |

## DECLARATION OF ORIGINALITY

March 27, 2016

Liliana Dhupelia

"I, LILIANA DHUPELIA, to the best of my knowledge, declare that this postgraduate dissertation has not been presented previously to qualify for a title, either in the same form or with variations, in this or any other university" Art 82 Advanced Learning.

Signature

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# INDEX

## LIST OF GRAPHS



## LIST OF FIGURES

# RESUMEN

A nivel global, se estima que un tercio de la población mundial vive en zonas donde no hay agua, o en zonas donde la presencia de  agua es muy limitada. El suministro de agua potable es cada vez más difícil debido a la creciente demanda, que se ve agravada por el crecimiento demográfico y el cambio climático global que deterioran la calidad del agua.

El Instituto Nacional de Salud de Colombia informó en el 2011 que la mitad de los Departamentos del país presentan contaminación en sus aguas. El informe muestra que sólo el 12.5% de los Departamentos en Colombia tienen agua potable,  a su vez el Sistema de Vigilancia de la Calidad del Agua Potable advirtió que el 15% de los Departamentos presentan un "alto riesgo" de agua. Muestras de agua en todo el país reveló la contaminación con cloro residual, microorganismos, E.coli y bacteria coliforme.

En este sentido los principales contribuyentes a la alteración de los ecosistemas, son actividades tales como drenaje, desvío de agua para riegos, uso industrial y doméstico, contaminación por presencia de  fertilizantes, residuos así como por la construcción de represas y la deforestación. Sobre este las industrias extractivas, en particular las industrias de exploración de petróleo y gas, que han ído incrementando la deforestación y desplazamiento de las personas y paralelamente la minería, especialmente la referida a la extracción ilegal de oro que ha sido un importante contribuyente a la contaminación de los suministros de agua y de la cadena alimentaria por el uso de químicos venenosos como mercurio y arsénico.

Colombia está en el proceso de establecer y adoptar una sólida base de investigación y desarrollo en el campo de la nanotecnología mediante la creación de grupos de investigación, redes y centros de excelencia. Antioquia tiende a ser líder en innovación y podría marcar el ritmo para el Departamento y para Colombia mediante la promoción y la inversión en I+D de tecnologías emergentes e innovadoras para sistemas eficaces de reciclaje de agua y purificación utilizando soluciones basadas en nanotecnología.

Por consiguiente la nanotecnología ofrece oportunidades para avanzar en el tratamiento de agua y aguas residuales, así como para aumentar el suministro de agua a través de un uso seguro de las fuentes de agua no convencionales. Por ello se recomienda que Colombia aumenta la inversión en I+D en el campo de la nanotecnología, en particular en tecnologías para el tratamiento y depuración de aguas.

**Palabras clave:** Nanotecnología, agua potable, escasez de agua, contaminación del agua, crecimiento demográfico, contaminación, nanomateriales, cambio climático global

## ABSTRACT

Globally, an estimated one third of the world's population lives in either water-scarce, or water-short areas. Worldwide, the supply of potable water is becoming more difficult because of the fast growing demand, which is exacerbated by population growth, global climate change, and water quality deterioration.

Colombia's National Health Institute reported in 2011 that half of the country's States have contaminated drinking water. The report shows that only 12.5% of the States in Colombia have potable water, with the Surveillance System for Potable Water Quality warning that 15% of States have "high risk" water in that samples of water nationwide revealed contamination with residual chlorine, microorganisms, E.coli and coliform bacteria.

Key contributors include activities that alter surrounding ecosystems, such as drainage, diversion of water for irrigation, industrial and domestic use, contaminating water with excess nutrient run-off (eg. from fertilizers) and waste, building dams, and deforestation. Extractive industries, in particular oil and gas exploration have resulted in increased deforestation and displacement of people. Similarly mining, especially illicit gold mining, has been a major contributor to the contamination of water supplies and the food chain with poisonous chemicals such as mercury and arsenic among others.

Colombia is in the process of establishing and embracing a strong research and development foundation in the field of nanotechnology by creating research groups, networks and centres for excellence. Antioquia tends to be a leader in the field of innovation and could set the pace for the State and for Colombia by promoting and investing in R&D for emerging and innovative technologies for effective water recycling and purification using nanotechnology based solutions.

Nanotechnology offers great opportunities to advance the treatment of water and wastewater as well as to augment potable water supply through safe use of unconventional water sources. It is therefore recommended that Colombia increases investment in R&D in the field of nanotechnology, particularly in technologies for the treatment and purification of water.

Keywords: Nanotechnology, potable water, water scarcity, water pollution, population growth, contamination, pollution, nanomaterials, global climate change

## INTRODUCTION

Colombia has enjoyed impressive economic growth in recent years. Nevertheless its rich biodiversity and ecosystems are coming under significant threat from extractive industries, livestock grazing, road traffic, mining and urbanisation. Also the conflict with the militia exacerbated many environmental pressures (illegal mining, drug crops and related deforestation), causing serious damage not only to the economic and social systems, but also to water reservoirs, rivers and wetlands.

The challenge we have as a society, not only in Colombia, is that it is extremely difficult to supply everyone with water: each of us need between 2 to 4 litres of water daily to survive, and the more active we are, and as the population increases, we will need more water (TEDxVirginiaTech, 2012). Globally it is therefore becoming increasingly more difficult to meet the demand for water.

Secondly, many of the world's most water-stressed areas will get less water due to world climate change, and water flows will become less predictable and more subject to extreme events. Human activities that affect the climate detrimentally include the burning of fossil fuels (oil, coal and gas) which release carbon dioxide gases into the atmosphere, affecting atmospheric balance and temperatures.

Globally, an estimated one third of the world's population lives in either water-scarce, or water-short areas, and climate change and population growth could see one half of the global population facing the same dilemma in the future (Shah, A. 2010) .

It is reported that, currently 97% of Latin Americans living in cities have a reliable source of drinking water - according to the World Bank. Whilst currently water appears to be "guaranteed" to most people in the region, the World Bank estimates that by the year 2030 there will be a deficit of 40% (Dinero. 2015).

Colombia is fortunate to have many fresh water sources compared with other countries. The problem is that, indiscriminately and without any conscience or law, Colombians are polluting rivers, lakes, sea and the air with waste such as cyanide, phenols, garbage, mercury and chromium.

Colombia’s National Health Institute reported in 2011 that half of the country’s States have contaminated drinking water. The report shows that only 12.5% of the States in Colombia have potable water, with the Surveillance System for Potable Water Quality warning that 15% of States have “high risk” water in that samples of water nationwide revealed contamination with residual chlorine, microorganisms, E.coli and coliform bacteria (Aronowitz, 2011).

Key contributors include activities that alter surrounding ecosystems, such as drainage, diversion of water for irrigation, industrial and domestic use, contaminating water with excess nutrient run-off (ie. from fertilizers) and waste, building dams, and deforestation. Extractive industries of oil and gas exploration have contributed to deforestation and displacement of people, and illicit gold mining has been a major contributor to the contamination of water supplies and the food chain with poisonous chemicals and mercury, especially in Antioquia.

Nanotechnology holds great potential in advancing water and wastewater treatment to improve treatment efficiency as well as to increase water supply through safe use of unconventional water sources, for example, innovations such as carbon nanotubes and flat carbon graphene sheets could be applied to alleviate the problem of water pollution and scarcity.

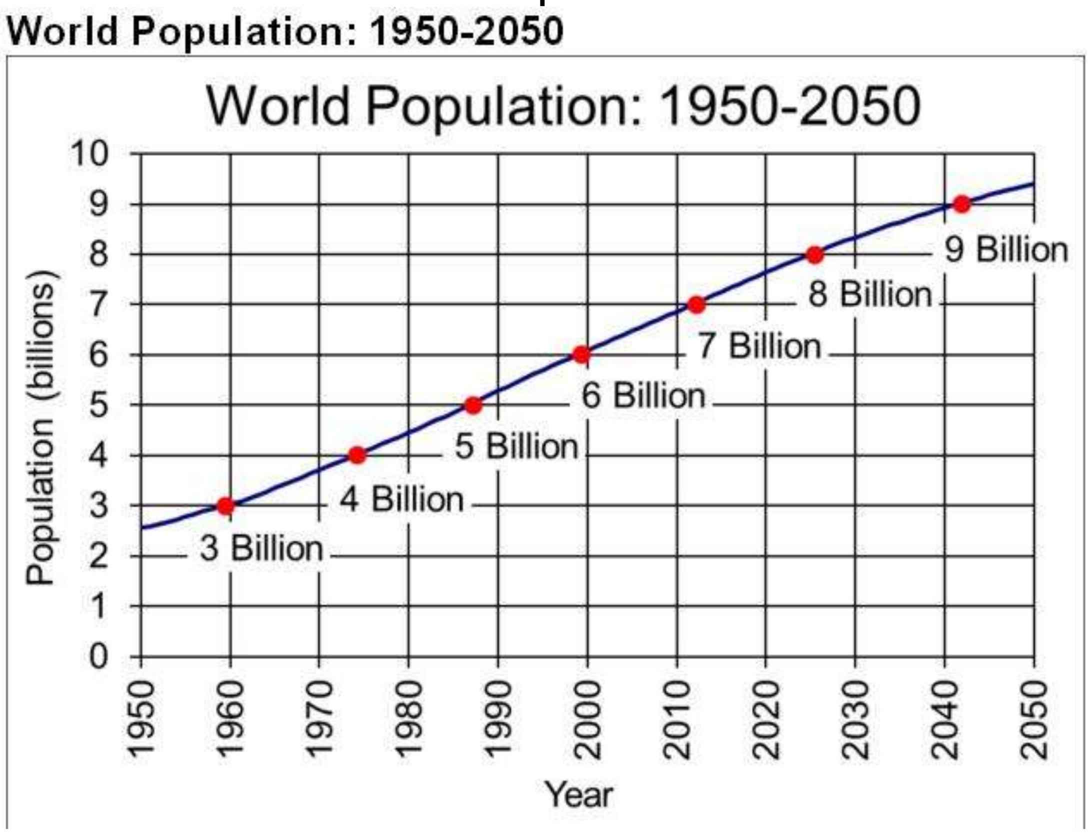
From Colombia’s perspective, the country is in the process of establishing and embracing a strong research and development foundation. In the field of nanotechnology there are intentions to leverage research groups, networks and research centres. Antioquia tends to lead in innovation and could set the pace for the State and the country by promoting and investing in R&D for innovative technologies that can be used for effective water recycling and purification systems using nanotechnology based solutions.

# 1. CONTEXTUAL REFERENCE

## 1.1 Global water scarcity and population

The challenge we have as a society is that it is becoming extremely difficult to supply everyone with water (figure 1). Humans need at least a minimum of 2 to 4 litres of water daily to survive, and the more active we are, and as the population increases, we will need more water (TEDxVirginiaTech, 2012). The current world population of 7.3 billion is expected to increase by approximately 30% to over 9.5 billion in 2050 (U.S. Census Bureau, 2015), as per graph 1.

**Graph 1**




Source: U.S Census Bureau, International Database, July 2015 Update.

Globally, it is becoming increasingly more difficult to meet the demand for water (figure 1). For example, South East Asia has rivers that are extremely contaminated; and India has already depleted most of its subterranean water with the result that people have to walk for hours to obtain water. Similarly, major problems exist in many countries.

**Figure 1**

**It is becoming more difficult to meet the demand for water.**

Source: http://www.globalissues.org/article/601/water-and-development#Thescaleofthewaterproblem.


Source: Nanotechnology Will Revolutionize Water Supply Sustainability, (TEDxVirginiaTech 2012)

According to UNICEF (Shah, A. 2010):

- An estimated 400 million children (1 in 5 from the developing world) have no access to safe water;

- Approximately 1.4 million children will die each year from lack of access to safe drinking water and adequate sanitation;
- Approximately 1.1 billion people in developing countries (about 15 percent of the global population) have inadequate access to water;
- Around 1.8 million children die each year as a result of diarrhoea; and
- 443 million school days are lost each year from water-related illness.

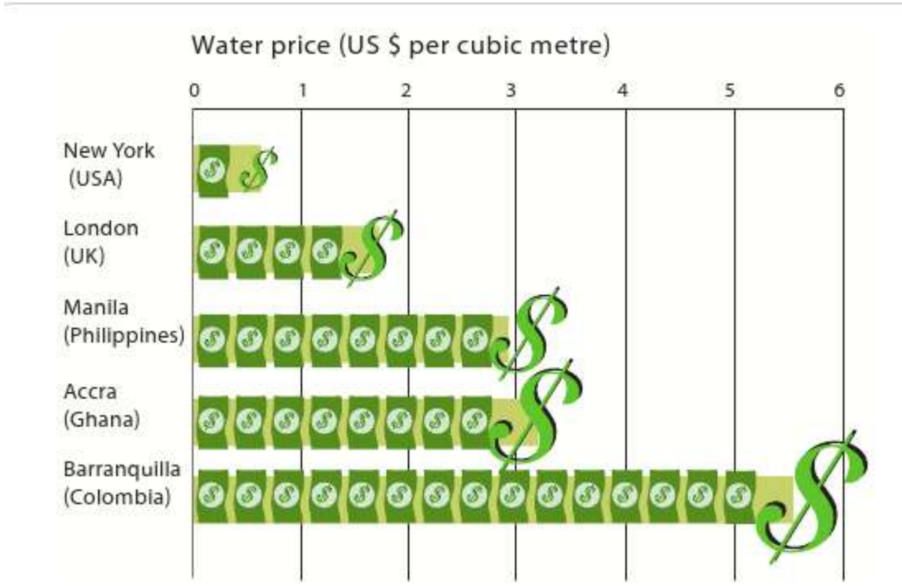
Besides, lack of water is closely related to poverty:

- Almost two in three people lacking access to clean water survive on less than $2 a day, with one in three living on less than $1 a day.
- More than 660 million people without sanitation live on less than $2 a day, and more than 385 million on less than $1 a day.
- Diarrhoea caused solely by inadequate drinking water, sanitation, and hand-hygiene kills an estimated 842,000 people every year globally, or approximately 2,300 people per day. (Dosomething.org, 2015)

It could be argued that privatization of water service management, often assumed as a basis for business efficiency, has instead led to reduced access for the poor around the world as prices for these essential services have risen. See figure 2. Shah (Shah, A. 2010), referring to figure 2, states that "if you live in a slum in Manila, you pay more for your water than people living in London". Hence, those living in poor conditions would find it even more difficult to access water, resulting in more illnesses and deaths related to lack of water and sanitation.

**Figure 2**

**Water and Development**




Source: Water and Development (Shah, A. 2010)

According to Shah, (Shah, A. 2010), an estimated one third of the world's population lives in either water-scarce, or water-short areas, because of climate change and population growth one half of the global population will face the same dilemma in the future.

Not only population increases are causing water shortages: "12 percent of the world's population uses 85 percent of its water, and these 12 percent do not live in the Third World." (Maude Barlow, 2001). Clearly then, it would seem that the affluent and educated society have poor regard for the value of water and the impact of their inaction for water conservation on those living in less fortunate circumstances.

## 1.2 World climate change, environmental issues and water security

Water is essential for life, and other competing uses are for agricultural, domestic and industrial purposes. The latter purposes cause water contamination due to excess nutrient run-off (eg. from fertilizers with harmful chemicals) and industrial waste. In addition ecosystems are altered when building dams, diverting water for irrigation, and due to deforestation. Besides, many of the world's most water-stressed areas will get less water due to world climate change, and water supplies will become less predictable and more subject to extreme events. Amongst the projected outcomes (UNDP, 2006. Pg 15):

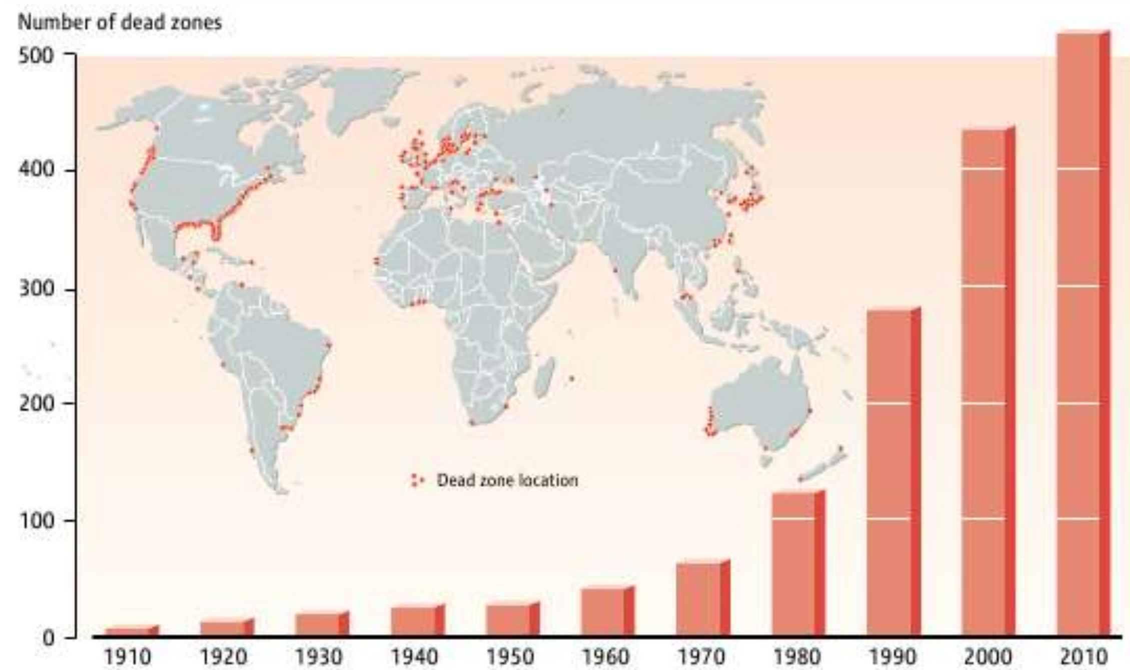
- East Africa, the Sahel and Southern Africa will experience severe reductions in water availability due to temperature rises and declining rainfall. The major consequence for basic food staples is potential productivity losses of up to 33% in maize and more than 20% for sorghum and 18% for millet.
- Food production systems could be disrupted such that an additional 75–125 million people will be exposed to the threat of hunger.
- Medium term water reductions due to accelerated glacial melt, affecting detrimentally the availability of water across many countries in East Asia, Latin America and South Asia.
- Monsoon patterns in South Asia could be disrupted resulting in fewer rainy days, hence, more people will be affected by drought.
- Increases in sea levels which would result in freshwater losses in river delta systems in countries such as Bangladesh, Egypt and Thailand.
- The effects of El Niño has for many months caused severe hardship in Colombia due to the intensity of the drought in the country. Already, the drought has affected 15,000 hectares of crops – causing prices to rise between 10% and 80% for basic commodities such as potatoes, tomatoes, maize and sugar cane ("Drought in Colombia Causes Food Prices to Skyrocket", 2016) .

In May 2010, the UN produced the 3rd Global Biodiversity Outlook report which notes "shallow-water wetlands such as marshes, swamps and shallow lakes have declined significantly in many parts of the world." (Secretariat of the

Convention on Biological Diversity, United Nations, 2010). The report also notes that “The number of observed ‘dead zones’, coastal sea areas where water oxygen levels have dropped too low to support most marine life, has roughly doubled each decade since the 1960s”. See graph 2.

**Graph 2**

**Global “Dead Zones”**

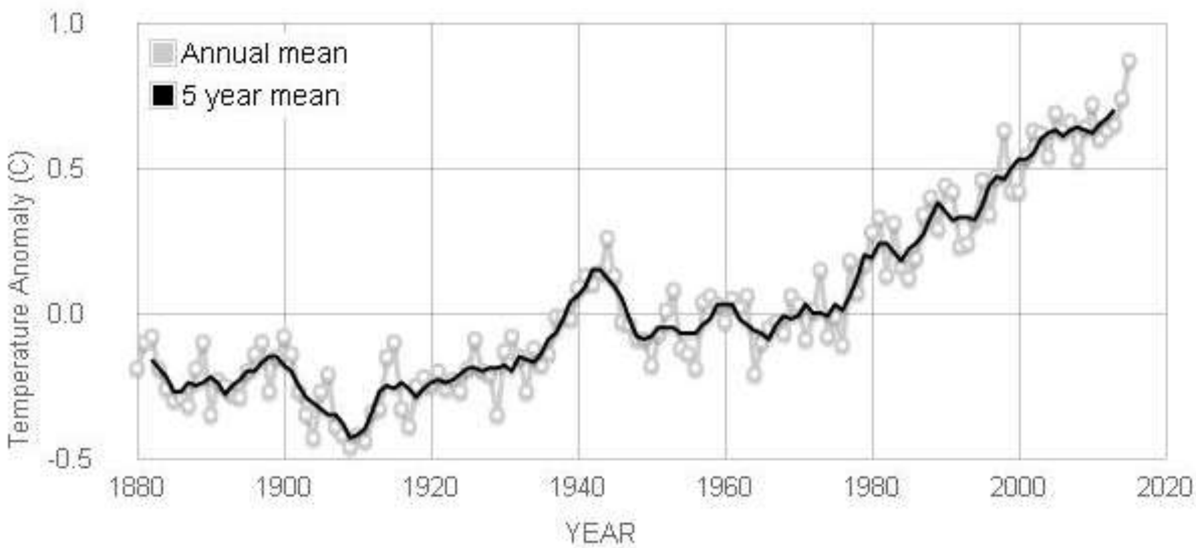



Source: Updated from Diaz and Rosenberg (2008). Science. Graph compiled by Secretariat of the Convention on Biological Diversity (2010) Global Biodiversity Outlook 3, May 2010, p60.

Although in the past, changes in climate were due to natural factors (solar radiation, volcanic eruptions, and the like), the current global warming is due mainly to human activity (Friks, 2012). Human activities include the burning of fossil fuels (oil, coal and gas) which release carbon dioxide gases into the atmosphere, and a by affecting atmospheric balance and temperatures through deforestation. These directly affect water availability and increase contamination through industrial and agricultural uses as discussed above.

**Graph 3**

**Global Temperature Index**




Source: NASA's Goddard Institute for Space Studies, 2015

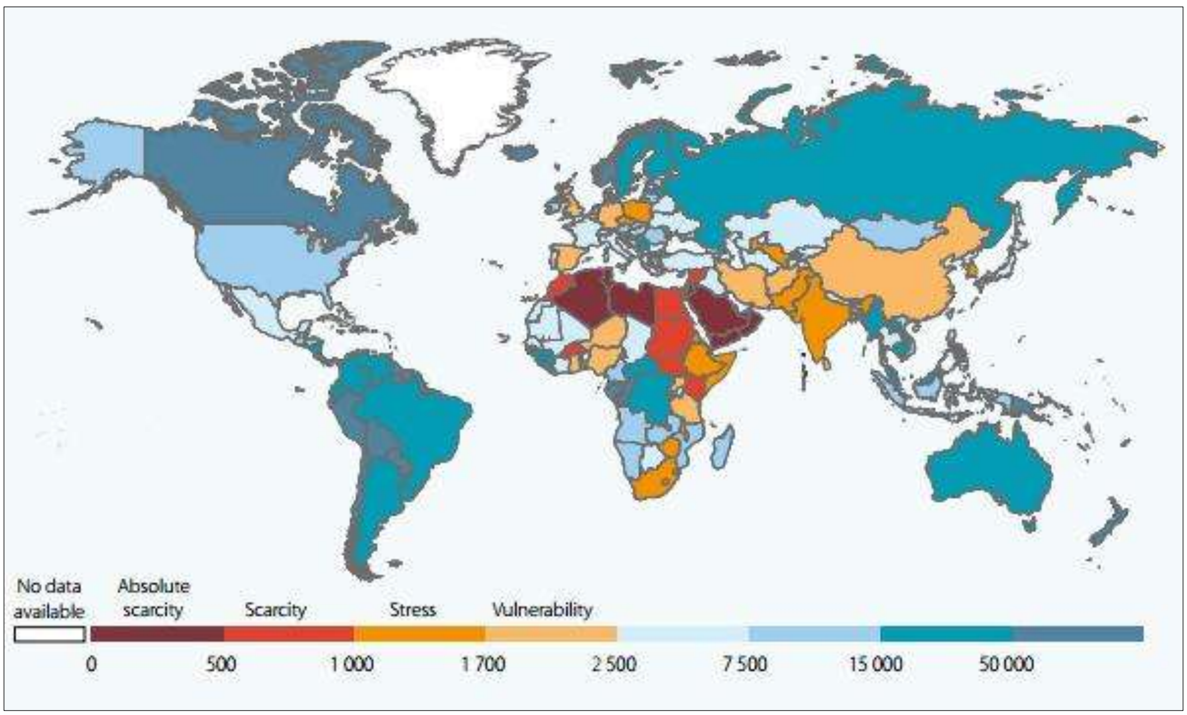
Graph 3 illustrates the annual change in global surface temperature. It also shows that the 10 warmest years in the 135 year record (ie. 1880-2015) all have occurred since the year 2000. Whilst annual changes varied by small fractions of a percent, the change in 2015 was the highest at +0.87 degrees Celsius and the trend is continuing at an alarming rate despite numerous "global summits" attempting to address the issues of climate warming.

It is no wonder that Asit K Biswas of the Third World Centre for Water Management, concludes that the world is facing a "crisis of bad water management". Global climate change, the environment, and security of water supplies are directly affected by human activity as shown above, hence, experts such as the US Central Intelligence Agency (CIA), the Ministry of Defence in United Kingdom and even some officials of the World Bank have made predictions a few years ago that the world's future wars could be fought not over oil, but for water (Interpress Service News Agency, 2006).

Due to human activity affecting climate change adversely, distribution and availability of freshwater resources mainly through precipitation can be erratic, with different areas of the world receiving varying quantities of water over any given year. Figure 3, based on compounded yearly averages, shows a significant variation in per capita water availability between countries (United Nations World Water Assessment Programme (WWAP), 2015).

**Figure 3**

**Total renewable water resources per capita 2013**




Note: The figures indicate total renewable water resources per capita in m3.

Source: WWAP, with data from the FAO AQUASTAT database, (http://www.fao.org/nr/water/aquastat/main/index.stm)

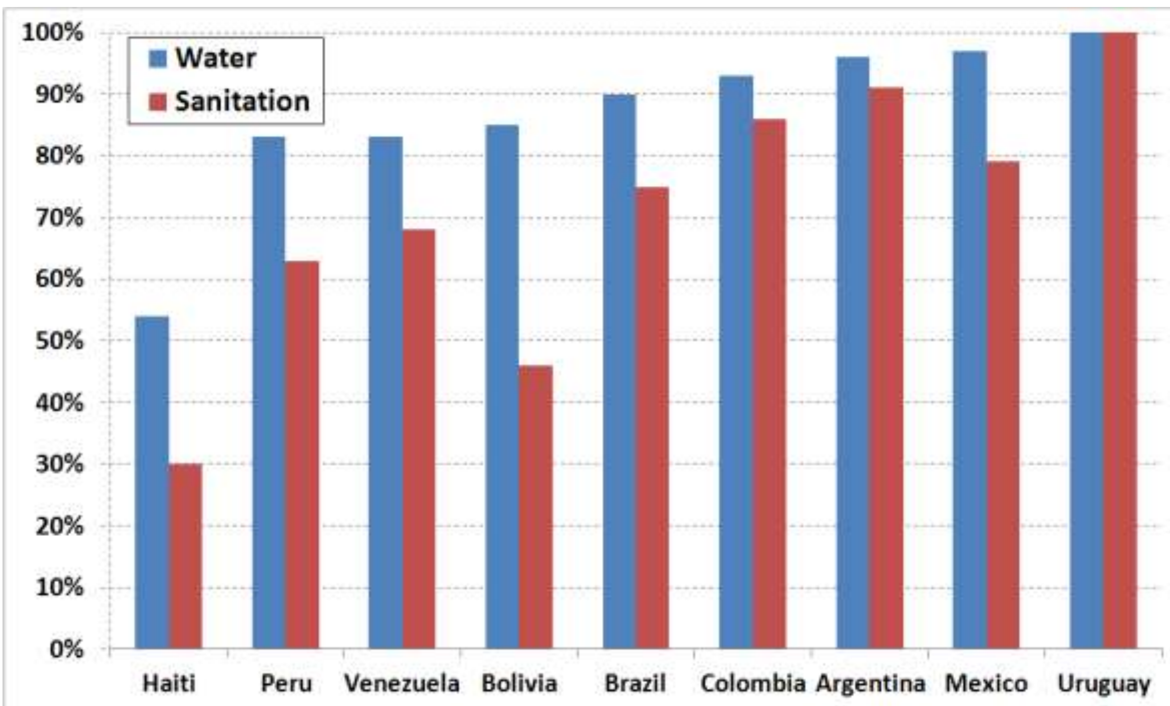
## 1.3 Latin America Perspective

### 1.3.1 Distribution problem

Approximately 50 million people (around 9% of the population) in Latin America and the Caribbean do not have access to a reliable source of drinking water (World Health Organisation, 2006). See graph 4.

**Graph 4**

**Water and Sanitation Coverage (broad definition) in selected Latin American countries in 2004.**




Source: World Health Organization (WHO/UNICEF 2006)

It is reported that, currently 97% of Latin Americans living in cities have a reliable source of drinking water - according to the World Bank. Whilst currently water appears to be "guaranteed" to most people in the region, the World Bank estimates that by the year 2030 there will be a deficit of 40%. Even though Latin America has one third of the world's freshwater supplies, paradoxically, it has three of the capital cities at severe risk of water shortage (Lima, Mexico City and Rio de Janeiro) (Dinero. 2015).

To further exacerbate the potential threat, a senior specialist in water and sanitation with the World Bank, Iris Marmanillo states that glaciers in the Andes of Ecuador, Bolivia and Peru have reduced in the last 20-30 years. These glaciers supply most of the rivers that support several villages in these countries and naturally, if these layers of snow melt, water levels would drop dramatically. In addition, 40% of potable water in the region is lost because of lack of quality infrastructure, affecting the poorest who are most at risk of shortages (Dinero. 2015).

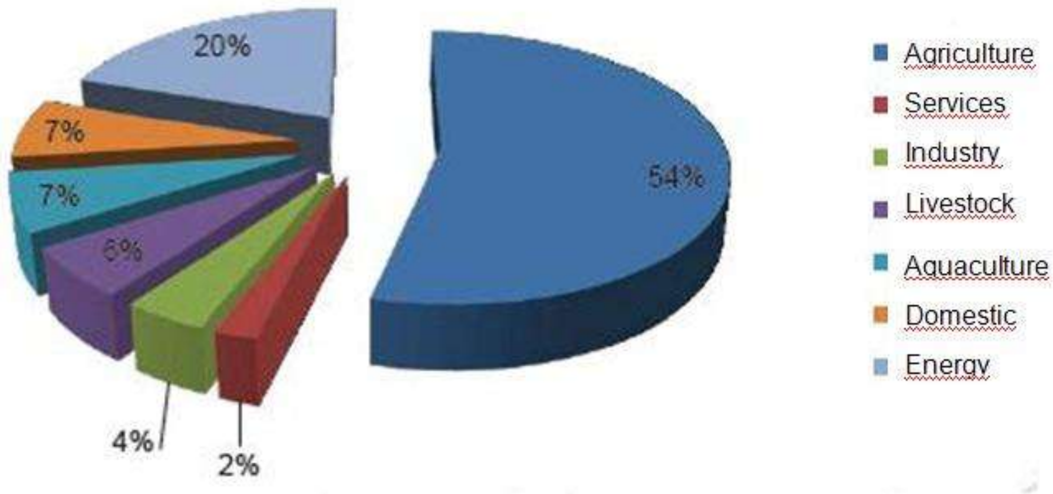
Finally, according to the Inter American Development Bank (IDB), water consumption in Latin America and Caribbean has increased to 75% in the last 20 years and could be 50% higher in the next two decades. (San Martin, O. 2002).

### 1.3.2 Colombia’s abundant water resources are under threat

Colombia is one of the countries with the highest water wealth in the world, however, most of this valuable resource is in places with low population levels such as the Amazon, Orinoco and Chocó, while in the Andina area, with the bulk of the population, there is only 15% of the total water supply (Ministry of Environment, Housing and Territorial Development, 2010). Demand for this water availability is shown in graph 5.

**Graph 5**

**Percentage Demand for Water by Sector in Colombia 2010**

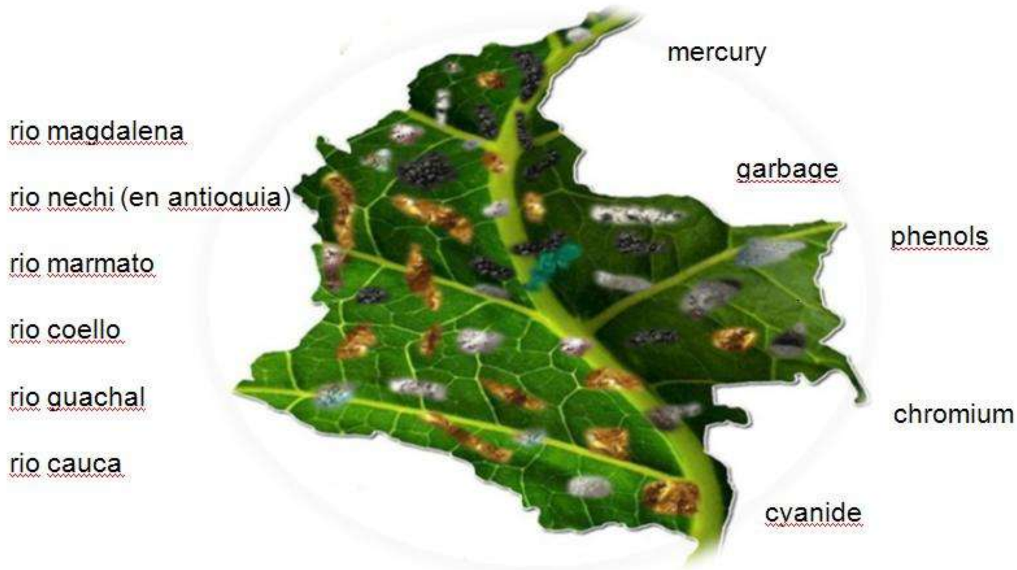



Source: (Centro de Ciencia y Tecnología de Antioquia - CTA, 2013 p.171.)

Colombia was considered to be the second most biodiverse country in the world, however, its natural heritage and the wellbeing of its people are under threat by the likes of extractive industries, farming and urbanisation (OECD. 2014). Colombia is fortunate to have many fresh water sources compared with other countries. The problem is that, indiscriminately and without any conscience or law Colombians are polluting rivers, lakes, sea and the air with wastes such as cyanide, phenols, garbage, mercury, chromium amongst others. Pollution is mainly generated by dumping, poor waste treatment, industrial waste and by inappropriate practices and habits of the users of water (Ministry of Environment, Housing and Territorial Development, 2010) See figure 4.

**Figure 4**

**Volatile Organic Compounds**




Source: image – Willian Arevalo

This contamination is starting to bring serious health problems as well as is affecting the economy especially in the fishing industry. Recent reports have found high concentrations of mercury in fish in the swamp of Ayapel, suspected through water transport of mercury. It is suggested that its origin is in the southern mining town of Bolivar (Antioquia) and in the upper part of the basin of San Jorge River (Cordoba) (Gonzalez, Ramos & Martinez-Tejada, 2015).

At least 80 municipalities in 17 States are under risk of serious health problems with increased incidences of birth defects, skin diseases and vision problems. It is reported that two municipalities of Antioquia, Segovia and Remedios, appear in the list of the most contaminated by mercury in the world (according to the Office of the United Nations Industrial Development Organization - Onudi) and that there have been at least 15 kidney transplants in the region in recent years due to mercury contamination (El Tiempo. 2014). See figure 5.

**Figure 5**

**Gold rush poisons water in 17 states of Colombia**


La fiebre del oro envenena aguas en 17 departamentos

El país no tiene datos sobre el número de personas intoxicadas por mercurio, metal usado en minería.

Source: el Tiempo (Agosto 2014)

Such is the problem of contamination of the Colombia's rivers that it is already affecting neighbouring countries (El Espectador, 2014). See figure 6.

**Figure 6**

**Alert in Brazil, Peru and Ecuador for mercury pollution in three rivers of Colombia**


NACIONAL 22 ENE 2014 - 9:48 AM

Alerta en Brasil, Perú y Ecuador por contaminación con mercurio en tres ríos de Colombia

La Unidad de Delitos contra el Medio Ambiente advierte que la salud de los habitantes de estas zonas se verá gravemente comprometida en unos años.

Source: El Espectador,(Enero 2014)

## 2. POLLUTERS OF WATER RESOURCES IN COLOMBIA

Colombia's National Health Institute reported in 2011 that half of the country's States have contaminated drinking water. The report shows that only 12.5% of the States in Colombia have potable water, with the Surveillance System for Potable Water Quality warning that 15% of States have "high risk" water in that samples of water nationwide revealed contamination with residual chlorine, microorganisms, E.coli and coliform bacteria (Aronowitz, 2011).

The main causes of water pollution on Colombian's water resources are depicted in figure 7 below.

**Figure 7**

**Causes of water pollution in Colombia**


Source: image – Yely Mildreth Rodriguez

## 2.1 Mining - legal / illegal

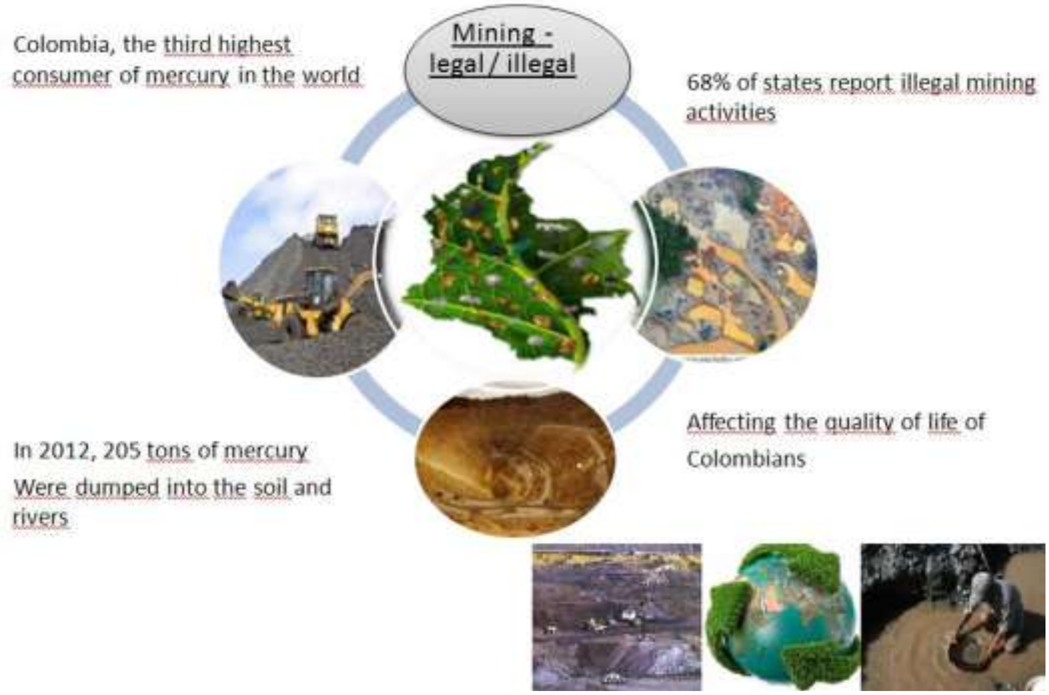
Colombia traditionally relied upon agriculture and manufacturing industry for economic development, and in recent decades the Government has decided enhance its economic position via the exploitation of natural resources, particularly oil and gold mining. This has contributed to the depredation of Colombia's natural resources and the environment, causing a huge social impact on and displacement of poor people living around these areas, so that mega mining projects could be established. See figure 8.

In just one example, in 2008 the Government struck a deal with the multinational AngloGold Ashanti (AGA) for the largest gold exploitation project in the history of Colombia; “Colosa”, whereby over 13 million hectares were awarded for gold exploration. (Desde Abajo, 2010). According to the Vice-President of AGA, (translated) “Colombia is a country with minerals, but not a mining country – it has to learn about mining in a sustainable manner so that it adds value to everyone” (El Tiempo, 2010).

In December 2013, the Colombia Solidarity Campaign published its Alternative Report entitled “La Colosa: A Death Foretold.” This report concludes that the threats to communities and the environment posed by AGA and the La Colosa mine have been drastically underestimated and it further highlighted the project’s negative impact on food and water security ie. through unreported violations of water/exploration permits and the unprecedented amount of waste that the mine is expected to produce (BM Colombia Solidarity Campaign, 2013).

**Figure 8**

**Mining - legal / illegal**




Source: image – Willian Arevalo

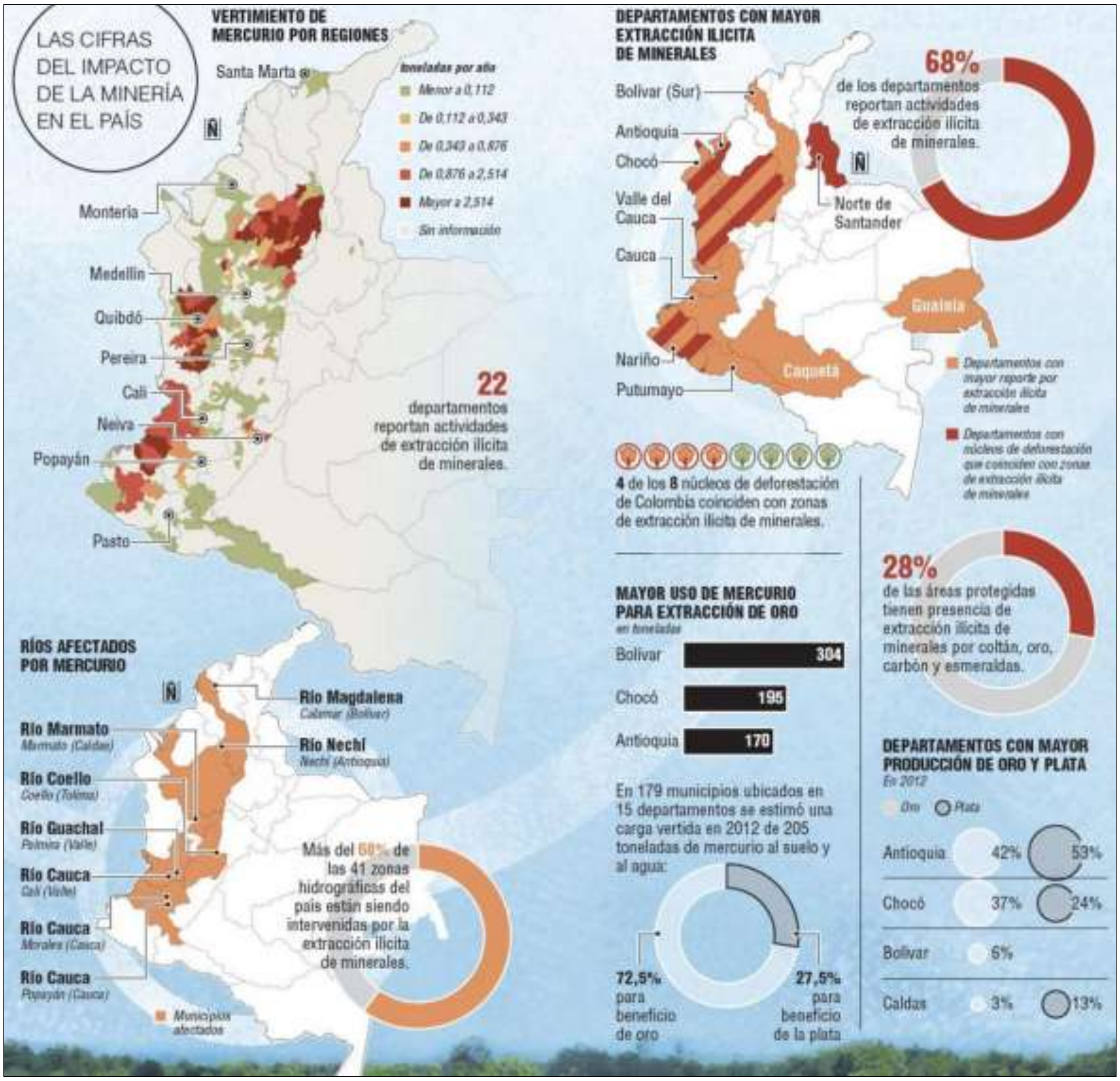
In Colombia there is rivalry in gold mining between foreign companies, artisanal mining and illegal miners, with conflict between the Government, criminal gangs and guerrillas who want to capitalize on mining activities. The impact of gold mining is huge - for 1 gram of gold, 8 tons of earth must be removed and to process the same amount of gold, one has to utilize and dispose into nature 14 times its weight with one of the most toxic and poisonous minerals – mercury (Especiales Pirry, 2013).

The high degree of mercury pollution in the Caqueta River due to illegal gold mining was a “wake-up call” for investigation by the Attorney General's Office, a situation which would also be reflected in the Inírida and Amazon rivers (El Especador. 2014). The effect of mercury poisoning on humanity has been discussed in Section 1.3.2 above.

See figure 9 for the state of mining activities and the impact of mercury in Colombia.

**Figure 9**

**Impact of Mining in Colombia**




*Source: Estudio National del Agua 2014 y Ministerio de Ambiente. Infografía El Colombiano, 2015*, (Correa, 2015)

On 15 Julio 2013, Congress passed the "Law of Mercury" (Ley No 1658) which is currently in the process of implementation. The Environment Minister mentioned "the criminal mining has grown significantly - six years ago this business did not have the dimensions it has today from the point of view of its sophistication - this industry moves 7 billion pesos a year.” (Correa, 2015). The Law of Mercury is in its early stages of implementation, however, recent news articles for example on 14 March 2016, (Ramirez Restrepo, 2016) show numerous operators of illegal mines have been arrested.

Mining is also one of the major contributors to the rapid deforestation of Colombia’s natural abundance. In 2014 alone, Colombia lost more than 140,000 hectares of natural forest, an increase of 16% over the previous year. Most affected States are Caqueta (29,245 hectares), followed by Antioquia (21,032 hectares) and Meta (13,727 hectares) (Correa, 2015).

Clearly, it can be concluded that the harm to humanity and the environment associated with extraction of natural mineral resources far outweighs the commercial benefits in Colombia. To address the situation, the Government passed late last year, Degree 2504 of 2015 to regulate and formalize operational and environmental aspects of mining activities in the country - endorsed by Santiago Angel Urdinola, President of the Colombian Association of Mining, who vetted for clear rules, legal certainty, and to curb the level of illegal mining (Activo Legal, 2016).

## 2.2 Environmental and social impact of oil

Oil operations are also causing water pollution and drought in regions like Casanare, where, prior to implementation of oil drilling and despite a hot climate, there was abundant water. Oil exploration in this State has resulted in almost 2,385 million litres of water being lost annually indirectly by oil operations creating environmental difficulties and social disasters which are beyond short-term repair (Especiales Pirry, 2013). However, according to the Vice-president of Conservation International Colombia, the issue of low water supplies cannot be attributed solely to the oil industry and that the situation in Casanare is not considered to be an environmental catastrophe (El Pais, 2014).

In just one example, Ecopetrol contaminated forty nine water wells, leaving 60 families in the district of Esmeralda without water (Espitia S. Vladimir, 2014). It would seem that a right to water has now become a fight for water in affected regions. See figure 10.

**Figure 10**

**Water or Oil?**


Source: (Especiales Pirry, 2013)

As recent as 2014, in order to increase oil reserves and production, the Colombian Government approved the use of non-conventional drilling and production techniques which are in trial stages in some countries; such as water injection, steam injection, injection of Carbon Dioxide, in-situ combustion and chemical injection (PWC Colombia, 2016).

In addition the Government approved fracking techniques and horizontal well drilling in September 2014 to overcome the hurdle of one million barrels per day. In several countries, these techniques have generated protests from environmental groups as the potential impact and the level of damage to the environment is unknown. Developed countries such as USA, France, Bulgaria and South Africa, amongst others, have suspended or banned these non-conventional techniques due to, for example, earth tremors caused directly by fracking. It is reported that there is a strong relationship between non-conventional drilling and increased seismic activity, let alone the large quantities of underground wastewater from the injection of liquid pressure on rocks to retrieve oil and gas (Rojas Trujillo, 2015).

Unless appropriate legislation is passed and enforced for the use of global best practices for oil exploration and drilling activities, there would be continual disregard for the impact on the environment and people competing for potable water supplies.

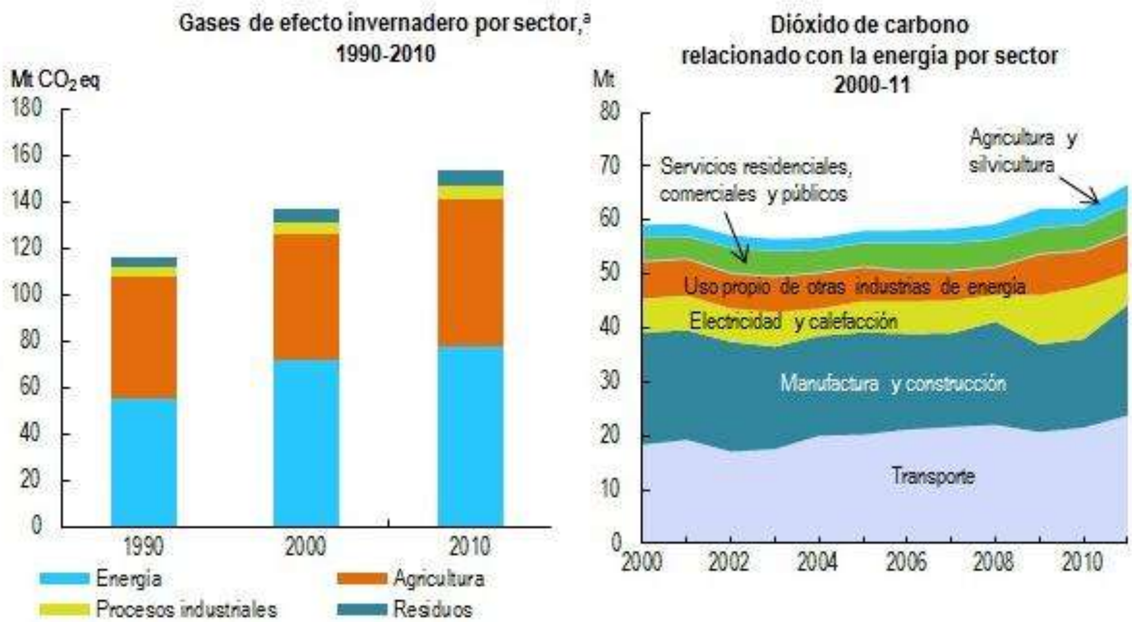
## 2.3 Agricultural damage to the soil and water resources

The main water sources for Colombians originate in the Colombian Andes, an area which is suffering contamination and at risk of drying up. Key contributors include activities that alter surrounding ecosystems, such as drainage, diversion of water for irrigation, industrial and domestic use, contaminating water with excess nutrient run-off (ie. from fertilizers) and waste, building dams, among others (Aronowitz, 2011).

Besides the contamination caused by transport in big cities, a third of emissions of greenhouse gases in Colombia are due to agriculture, mostly in the form of methane generated by livestock, and also nitrous oxide emissions due to the use of fertilizers (OECD/ECLAC, 2014). See graph 6.

**Graph 6**

**Emissions from Fuel Combustion Statistics**




Partial estimate includes emissions from land use and forestry, and use of solvents. In the estimate of the International Energy Agency to the total emissions of greenhouse gases there is the "other" category includes emissions from forest fires and decomposition of biomass remaining on the ground after felling forests and deforestation.
Source: OECD-IEA (2013), IEA C02 Emissions from Fuel Combustion Statistics (database)

Millions of tons of pesticides are used for agriculture annually. For example, within industrial coffee production pesticides are deployed which often consist of chemicals that seriously affect health and ecology. “Sampling of imported green coffee beans conducted by the U.S. Food and Drug Administration (FDA) in the late 1970s and early 1980s revealed frequent detections of DDT, BHC (benzine hexachloride) and other pesticides banned in the U.S. because of possible carcinogenicity or long-term persistence in the environment” (Hearne Shelley A. 1984). Similar chemicals continue to be used as of current day.

Only recently the Colombian Government has decided to abstain from using environmentally unfriendly herbicides such as glyphosate for spraying eg. for the fight against marijuana and coca cultivation. Glyphosate has been linked as a cancer-causing agent due to decades of use in Colombia. Regardless, such pesticides have had the result of long term contamination of soil and water due to run-offs in rivers and ecosystems (El Colombiano, 2015).

## 2.4 Dumping of garbage, plastics and other industrial waste

Colombia is considered to be one of the most biodiverse countries in the world, however, its rich natural heritage is under increasing threat of pollution from the likes of extractive industries, livestock, urbanization and the use of cars, according to OECD (OECD/ECLAC, 2014).

Industrial pollution can be harmful, toxic or hazardous, directly or indirectly. Types of these emissions (legal or illegal) include:

- Emissions into the atmosphere
- Discharges of wastes and chemicals into public sewers and rivers
- Discharges to ground or surface water channels
- Storage or disposal of toxic or harmful industrial waste
- Emissions from internal combustion engines in many transport systems; typically cars, buses and trucks in big cities and urban zones

Paradoxically, the technology used to modify the environment for human advantage, at the same time has contributed to damaging the environment.

Colombia has tried to curb the discharge of industrial waste into wastewater systems by introducing a wastewater discharge fee system in the late 1990's, ("Ley 99 de 1993 Nivel Nacional", 1993) where companies were charged a fee based on the amount of pollutants discharged into the environment. There are mixed views on the effectiveness of this program (HydrateLife, 2014). According to this report, between 1997 and 2002 only 27% of the fees were collected.

## 2.5 Water sewage systems obsolete / disrepair

In 2013, regulators in Colombia inspected 333 of Colombia's 562 wastewater treatment facilities. Of the 333 inspected, 89 facilities (27%) were found to be inoperable. The study further revealed that:

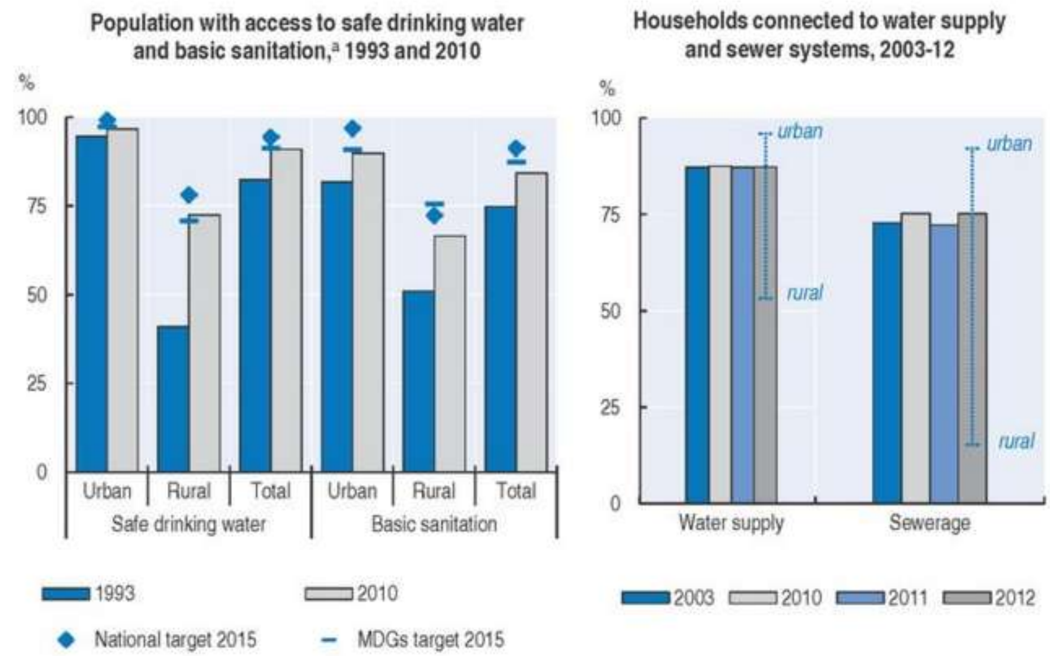
- Infrastructure was not being maintained at optimum levels.
- Sewage disposal regulations were not being adhered to.
- Operators did not have sufficient knowledge of operating protocols.
- The facilities were vulnerable to natural disasters.

Colombia's public services regulator deployed an action plan to train staff as well as improve operations, maintenance, and optimization of the systems (HydrateLife, 2014).

Graph 7 below shows progress made for initiatives to provide safe drinking water and sanitation to urban and rural households in Colombia. However, there still remain gaps as the population increases / are displaced.

**Graph 7**

**Access to Water and Sanitation in Colombia**




*a)* Includes wells and septic tanks.
*Source:* DANE (2012, 2010 and 2008), *Encuesta Nacional de Calidad de Vida*; Government of Colombia (2012), *Informe de Seguimiento. Objetivos de Desarrollo del Milenio*; IDEAM, 2012.

The situation is summed up by Senator Jorge Enrique Robledo, that there are more than 800 municipalities without constant, quality water supplies – and that this is not due to scarcity by the physical absence of water, but by the incompetence of the Government to bring it (water) to the communities (Robledo, 2016).

# 3. REMEDIATION

Even though Colombia has enjoyed impressive economic growth in recent years, its rich biodiversity and ecosystems are under significant threat from the likes of extractive industries, agriculture, and mining. Also the internal conflict in the last 55 years exacerbated many environmental pressures (illegal mining, drug crops and related deforestation), causing serious damage to the economic and social systems (OECD/ECLAC, 2014).

Colombia is highly committed to climate change obligations by adhering to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Copenhagen Accord. According to Conservation International – Colombia, the country has decided to adopt a low carbon production strategy, and the REDD+ program (Reducing Emissions from Deforestation and Forest Degradation) ("Mitigation |Conservation International", 2013).

To address the problem of contamination of water resources, Colombia has the opportunity to remedy, strategise and seek solutions, before it is way too late. Some possible solutions include:

- Eco friendly environmental awareness - changing bad habits.
- Better control over resources, regulatory compliance and enforcement to bring environmental policies and institutions in line with best international practices.
- Oblige related industries to build treatment plants for wastewater from their plants.
- Incentivize usage of rainwater.
- Desalination – similar to the United Arab Emirates which has deployed these systems since the 1960s, a process which uses reverse osmosis, in which seawater is forced under pressure through

a membrane that strips out the salt (Gomall, 2015). However, for Colombia this could be a very expensive option to transport water from the sea to inland areas, though this could be a feasible alternative for the many coastal regions in the country.

- Investigate use of new technical developments and innovations eg. as trialed in the USA, covering the water with shadeballs which are used to cover the surfaces of reservoirs to block out sunlight and thus reduce evaporation (Quinones, 2015). See figure 11.

**Figure 11**


Source: Latinamericanscience, http://latinamericanscience.org/shadeballs-or-floating-solar (Quiñones, 2015)

- Reuse of wastewater – finding new technological advances for the ever-increasing wastewater produced by industries and households, to be treated and reutilized for human consumption, industry and agriculture. In this regard nanotechnology could be used for filtration of water fit for human consumption (Berger, 2014).

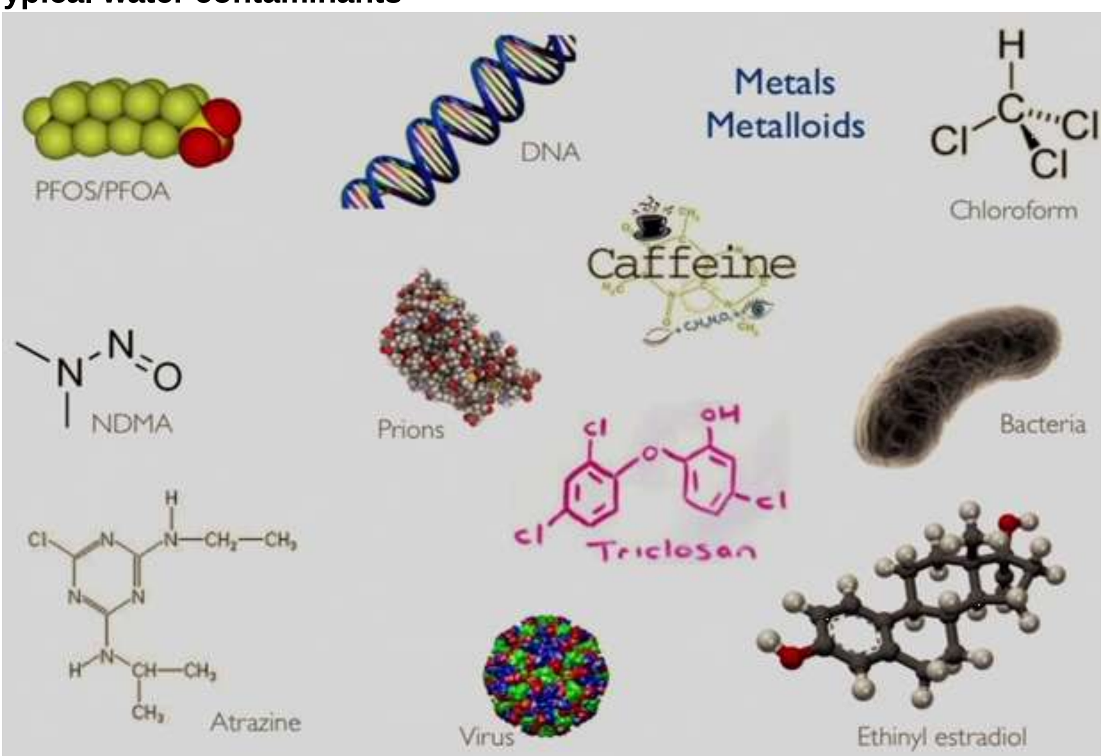
It is imperative for Colombia to discover and invest in emerging technologies, such as nanotechnology, that are cost effective and can help remedy the contamination of water resources.

## 3.1 Nanotechnology will revolutionize water supply sustainability

The reuse of waste water poses a major challenge; these waters could contain many contaminants such as, viruses, blood, waste, chemicals and other toxics. The challenge is to ensure the total eradication of these contaminants to render the water safe for reuse. See figure 12,

**Figure 12**

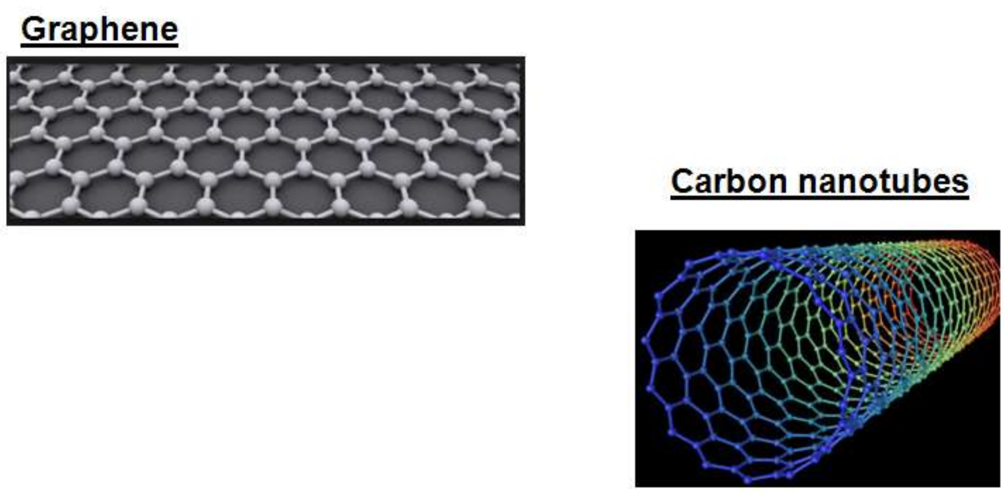
**Typical water contaminants**



Source: TEDxVirginiaTech (2012).

Nanotechnology can be used to detect and remove these contaminants. In the last twenty years there have been substantial increments in the field of nanotechnology and its applications. Current scientific developments, such as carbon nanotubes (CNT) and flat carbon graphene sheets, which were not available 10 years ago can be applied to alleviate the problem of water pollution and scarcity. Carbon nanotubes (CNT) are tiny hexagonal tubes, made by rolling sheets of graphene (see figure 13) - requiring little energy and can be designed to specifically reject or remove not only salt, but also common pollutants such as organic, inorganic and biological water pollutants (Das et al., 2014).

**Figure 13**




Source: image - https://www.google.com.co/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=carbon%20nanotubes%20pics

There are innovative companies which have begun specializing in purifying polluted water and are investing further in research and development through nanotechnology. Examples of some of these advances follow.

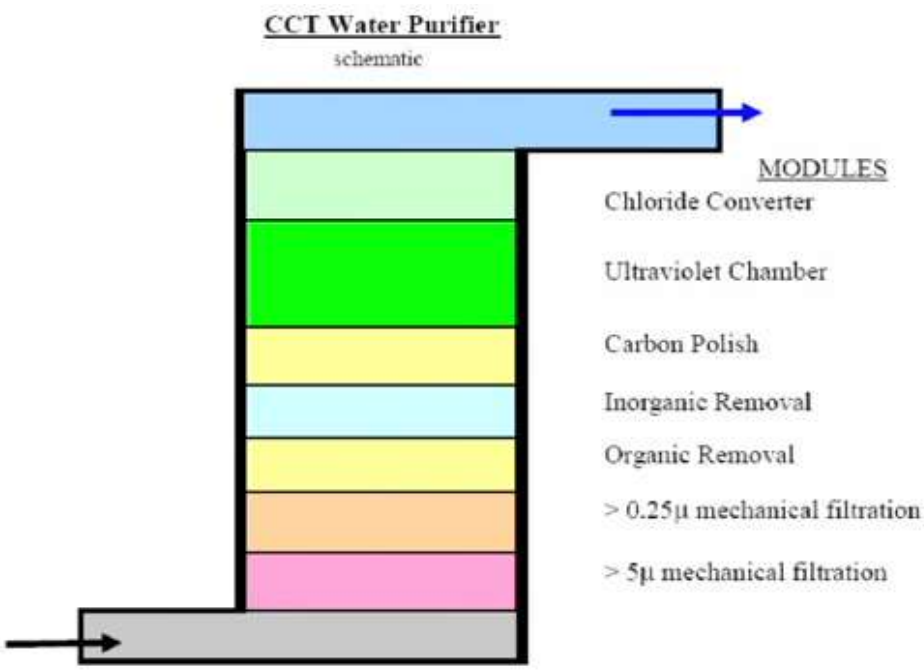
Crystal Clear Technologies in the USA have developed a portable water purification system for the U.S. Army. (The Green Economy: Nanotechnology Cleans Water, 2011).

**Figure 14**

**Crystal Clear Technologies laboratory**

Source: image- https://www.youtube.com/watch?v=Ukf74pJes7Q, (2011)

The Crystal Clear Technologies system has been designed to eradicate all pathogens, bacteria, viruses, parasites, heavy metals, pesticides amongst others. See figure 14.




Source: image- https://www.youtube.com/watch?v=Ukf74pJes7Q, (2011) NASA promoted the creation of small portable water filters that do not require much power and allow astronauts to reuse their waste water on the spacecraft. Alan Cummings is the CEO of a startup company called Seldon Technologies that specialises in nanotechnology processes to clean dirty water. They invented the "Seldon Water Sticks" filter system which was designed for use by astronauts. This technology uses carbon nanotubes to address one of the biggest challenges for space flights, which is to have adequate water for astronauts to use when travelling in space, for bulk water is heavy, consumes space and adds weight to the spacecraft (figure 15) (NanoNerds, 2011).

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**Figure 15**

**Seldon Technologies Water Sticks System**

Source: image – Cleaning our water with nanotechnology, (NanoNerds, 2011)

Michael Preacher, UK engineer and inventor, created the "Lifesaver Bottle" a simple device that can be used to purify water such that can be drinkable. It was especially invented to aid people in disaster situations (figure 16) (TED Talks, 2009).

**Figure 16**

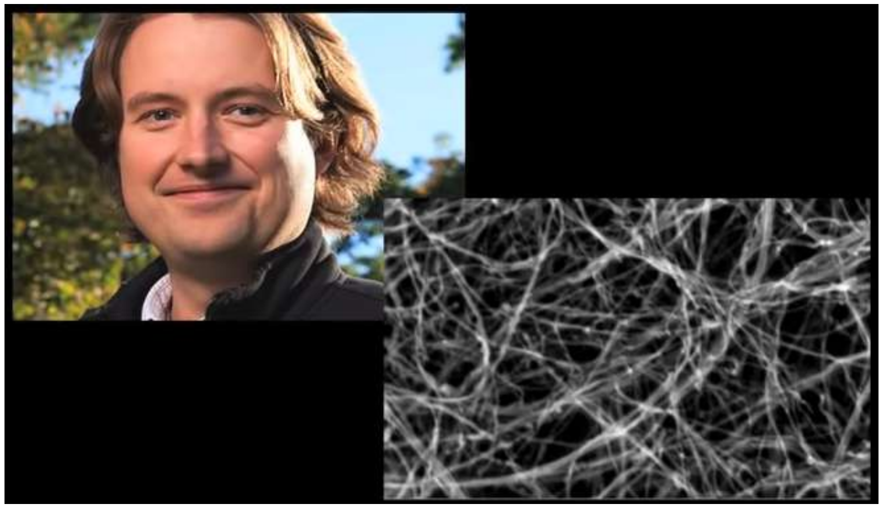
**Michael Preacher's "Lifesaver Bottle"**


Source: image – Cleaning our water with nanotechnology, (NanoNerds, 2011)

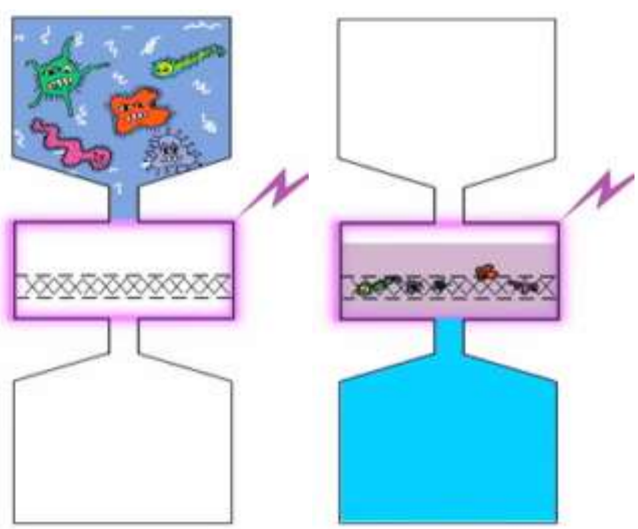
The only issue with filters, whether you use nanotechnology or not, is that they need regular replacement when the filter is saturated with the accumulation of bacteria. To address this problem, Charles Besidas (figure 17), a nanotech researcher at Harvard University formulated a self-cleaning filter. He conducted electricity through the nanotube (electrochemistry) which destroyed all the adherents in the filter (NanoNerds, 2011). As a result the filter stayed clean for longer and did not need replacement or regular cleaning.

**Figure 17**

**Charles Besidas, a nanotech researcher at Harvard University**



Source: image – Cleaning our water with nanotechnology, (NanoNerds, 2011)

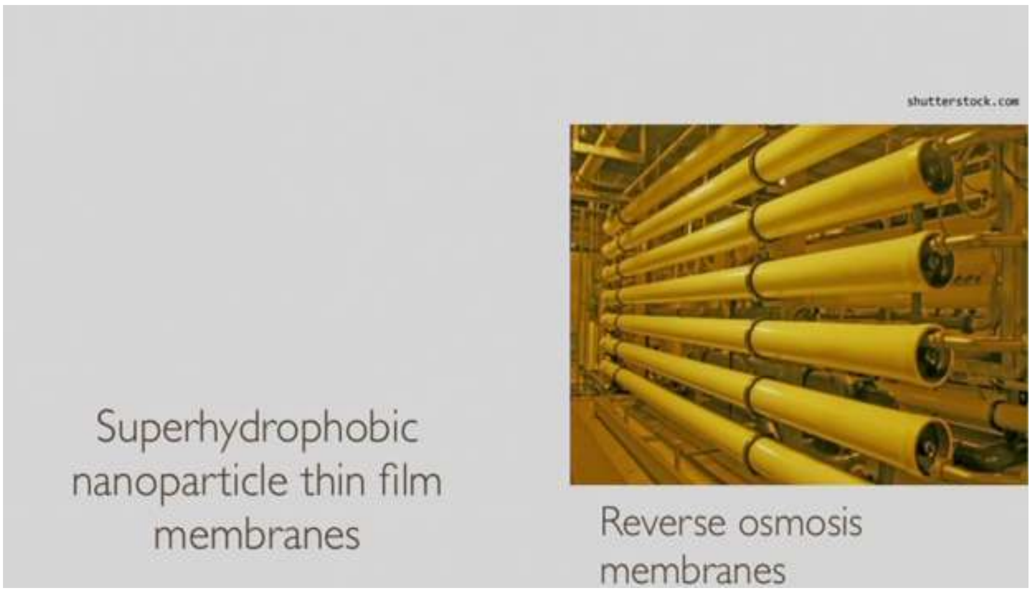


Source: image – Cleaning our water with nanotechnology, (NanoNerds, 2011)

Around 96% of the Earth's water supply is in the oceans but desalination is an expensive process. The United Nations estimates that around 1.1 billion people do not have access to water treatment facilities. This is further exacerbated in areas where population increases result in demands for water that exceed the amount of water available in rivers and lakes. Reverse osmosis is a process of forcing saltwater molecules through nanomaterial membranes to produce clear water. Reverse osmosis membranes (figure 18) also removes harmful bacteria. Another desalination process called capacitative deionization could be potentially more cost effective than reverse osmosis (Booker & Boysen, 2005).

**Figure 18**

**Reverse osmosis membranes**




Source: TEDxVirginiaTech (2012).

## 3.2 State of Science in Colombia

At the 2015 forum, “State of Science in Colombia”, some of Colombia’s most influential researchers, experts, institutions, universities, business men, and selected guests, agreed that the key to boost Colombia’s economy is to increase investment in research, technology and innovation.

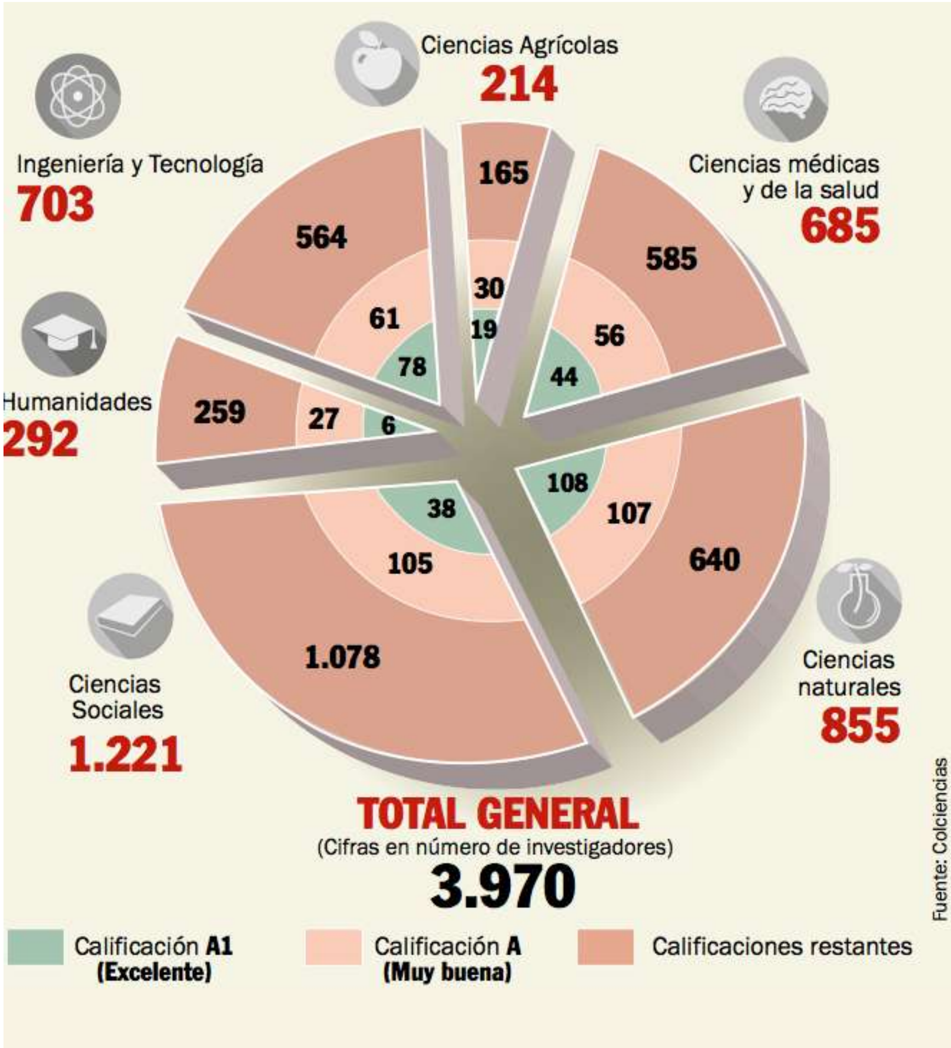
According to Eduardo Posada (Foro Semana, 2015), president of the Colombian Association for the Advancement of Science, investment in the sector is very low compared to other countries in the region and alarmingly low when compared to the world. It is therefore necessary to stimulate investment in the productive sector, promoting new technology-based companies.

Felix de Moya Anegón (Foro Semana, 2015), principal investigator and coordinator of the SCImago Group and coordinator of the Atlas of Science for Colombia project stated: *"With the exception of Brazil, Latin American countries have low investment budgets for science. Between 2003 and 2013 Colombia grew more than 500% in research sectors, however, Colombia still invests 700 times less than the U.S. in research."*

Graph 8 shows the level of Colombian researchers in their respective areas of research focus. Only 7.3% of the research groups are classified as “Excellent (A1)”.

**Graph 8**

**Level of Colombian reserachers in respective areas of knowledge**




*Source*: ("Forum: 'El Estado de la Ciencia en Colombia,'" 2015).

Public policies and funding have been accompanied by a common rhetoric in LAC countries that emphasize the potential of nanotechnology for increasing competitiveness in the context of a globalized, technology-intensive economy. (Foladori, 2012, pp.2-3).

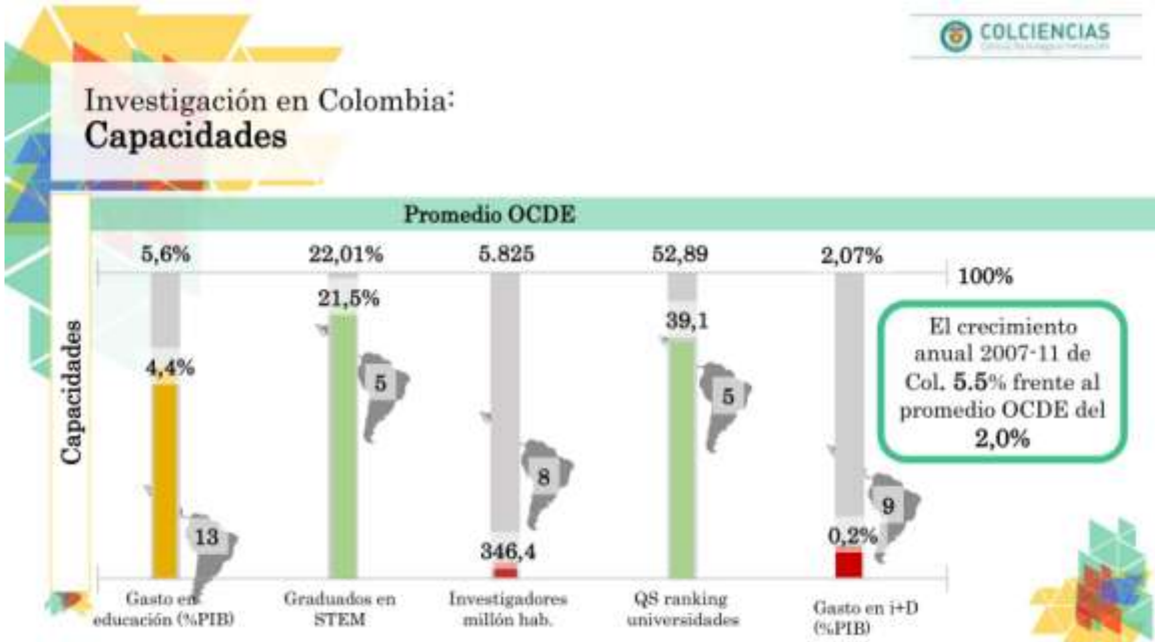
Colombia, in the last decade, has created research groups (20), research centers (2), a National Council for Nanoscience and Nanotechnology (created in 2005), a Network of Research and Development Nanotecnosciencias (made up of universities and research centres). In addition, a Centre of Excellence was established in New Materials-CENM for promoting R&D in nanotechnology, and a Center for Science and Technology Nanoescalar-Nanocitec investigating nanotechnology applied to the field of medicine with special emphasis on cancer (Electrónica et al., 2007, p.19). Most recently a new initiative, the National Nanotechnology Centre was propagated in Medellin in order to create a collaborative network and a big platform of scientific structure in Colombia for solving targeted issues via nanotechnology including energy, food, water, medicine amongst others.

The Forum for East Asia Latin American Cooperation FEALAC is a conference where 20 countries in Latin America and 15 countries in East Asia participate. Colombia and Japan have recently been appointed co-chairs of the Working Group on Science, Technology, Information and Education. In March 2016, an International Workshop “Bio-nano Convergence Network – Phase 2” was staged in Colombia to discuss action plans for the formulation of nanotechnology projects, sources of financing and participation by member countries (Cbionano Network, 2016).

Graph 9 shows the growth of Colombia in areas of different skills in 2015 – with an annualized average growth of 5.5% (2007-2011) compared to the OECD countries’ overall average growth of 2.0% for the same period.

**Graph 9**

**Research in Colombia: Capabilities**



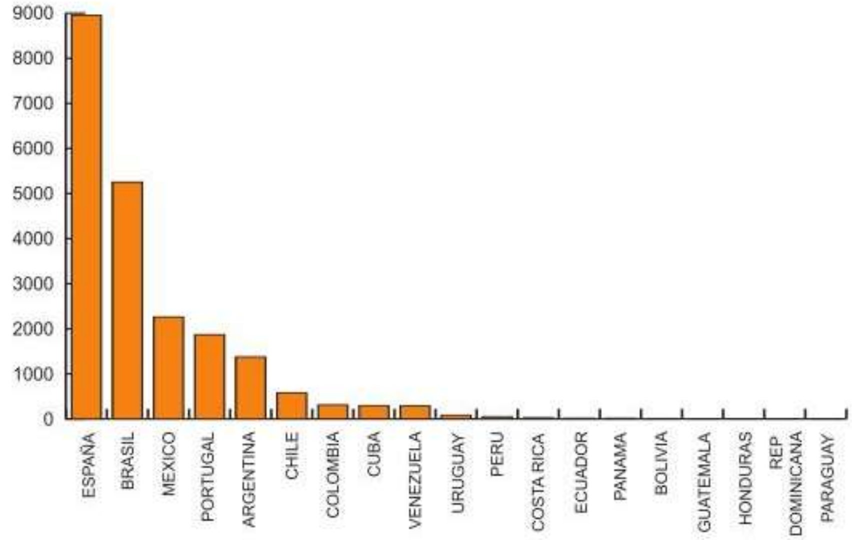

*Source*: ("Forum: 'El Estado de la Ciencia en Colombia,'" 2015).

## 3.3 Nanotechnology in Colombia

Graph 10 below shows the share of each country's participation in nanotechnology scientific publications – Iberoamerica, a cumulative total of scientific articles and publications in nanotechnology published from 2000 to 2007.

**Graph 10**

**Publications of Countries from Iberoamerica on Nanotechnology**




Note: Accumulated 2000-2007 *Source:* (Barrere et al., 2010)

According to this report released in 2010 (Barrere et al, 2010) with reference to the graph above, the following are standings in the number of publications in nanotechnology:

| COUNTRY | CUMULATIVE NUMBER OF ARTICLES ON NANOTECHNOLOGY 2000-2007 |
|---|---|
| Spain | 8,955 |
| Brazil | 5,254 |
| Mexico | 2,261 |
| Portugal | 1,869 |
| Argentina | 1,376 |
| Chile | 581 |
| Colombia | 311 |
| Cuba | 296 |
| Venezuela | 291 |
| Uruguay | 83 |
| Peru | 50 |

Although no updates were available to this study, as a preliminary conclusion, Colombia appears to be lagging behind regionally and globally in the field of

R&D and investments in Nanotechnology (and innovation generally) for economic, environmental and social benefits.

On the other hand, Colombia was ranked 60$^{th}$ out of 142 in the Global Innovation Index (GII) in 2013, in 2014 it dropped to 68$^{th}$ out of 143 (Global Innovation Index 2014, n.d.), and ended at 67$^{th}$ out of 141 in 2015 (World Intellectual Property Organization, 2015). Further, it has been reported in 2014 that Colombia's GDP was the fastest growing in Latin America and, at the time, the fourth fastest growing in the world (Egusa, 2014).

In the field of nanotechnology, in Colombia there exists a gap between research efforts and needs of industry and users, due to a fragmentation of efforts, whereby government, universities and private enterprises investing in nanotechnology in Colombia are dispersed. Broader challenges that hinder the development of nanotechnology and its commercialization include factors such as safety, regulations, standardization issues, financing innovation, technology transfer (Martínez, Vladimir, Mejia Sergio, Jaramillo Franklin, 2014).

Nanotechnology developments can be applied to a broad spectrum affecting just about every aspect of our lives – a scope which needs to be narrowed to country specific needs and capabilities as far as Colombia is concerned.

## 3.4 Water purification advances in Colombia

Colombia has been blessed with sufficient water supplies, however, the wastewater treatment systems require revision and maintenance (as discussed in Section 2.5 above). According to graph 6 in Section 2.5 above, Colombia is reported to have water coverage of 97% in urban areas and 76% in rural areas.

The low coverage in rural areas could be aggravated by the current severe drought, and also due to displacement of people due to internal conflict in recent years. “The reference UN figures say 150,000 to 200,000 people are being displaced per year” (HydrateLife 2014). This makes it difficult for the provision of utilities and clean water supplies.

In Section 2 above, it was shown that that only 12.5% of the States in Colombia have potable water, with the Surveillance System for Potable Water Quality warning that 15% of States have “high risk” water (Aronowitz, 2011). Whilst efforts are being made to address the main causes of water pollution shown in Figure 7 above, there still remains a lot of work to be done. Mining, especially illegal mining, continues to thrive despite the ongoing battle against this activity, and discharges of mercury into the water basins and rivers are not as yet able to be curbed.

A Strategic Master Plan or Roadmap would need to be developed by the Government to address the provision and quality of water and sanitation in Colombia, in a way that exploits current conventional technologies and new nanotechnologies to ensure access to potable water by the majority of the population.

## 3.5 The Dilemma for Antioquia

Antioquia, on the one hand, is endeavouring to make a lot of progress to provide potable water and for the treatment in wastewater especially in urban areas. One initiative, as part of the cleanup of Medellin River, construction has commenced on the Bello Wastewater Treatment Plant, which, when completed, will process more than 75% of residential wastewater, covering 95% of the overall wastewater discharged into the Medellin River (Negarin, 2015).On the other hand, as discussed in Section 2.4 above, there remains the ongoing difficulty in curbing the dumping of industrial waste and industrial wastewater into the rivers and creeks of Antioquia. There still remains the difficulty of supplying potable water to all rural areas.

The following are a few examples of reported incidences of water contamination and lack of potable water in rural areas in Antioquia.

- According to a report by United Nations Industrial Development Organization (UNIDO) Antioquia has around 13,000 people directly involved in gold business which is attractive to the rural community (Veiga, 2010) where it is reported by DANE IN 2009 that at least 62% of the rural population live in poverty (Perfetti, 2009). The UNIDO report further states that according to the Mayor of Zaragoza, more than 97% of the mining activities in the region are illegal. The report further highlights that mercury losses from illegal gold processing are substantial and released into local creeks in the toxic form of mercury cyanide (Veiga, 2010).
- As recent as November 2015, around 14,000 residents of the poverty-stricken district of Granizal, occupied by displaced persons in rural Bello (North of Medellin) filed a class action to demand the construction of an aqueduct to provide potable water, as they were “drinking water of the dead” (translated from “tomamos agua de muerto”)”. After 15 years of frustration, the residents are now demanding their constitutional right to potable water (Ospina Zapata, 2015).
- Further in the last week of November 2015, Empresas Publicas de Medellin (EPM) interrupted the water supply in the municipality of Caldas (South of Medellin) as a precaution for fear of possible contamination. Residents of Caldas reported a strange taste and a gasoline type of odour in the water supply (Valdes Ángel, 2015).

Antioquia has four large river basins that ensure abundant water supply: Middle and Lower River Cauca; Middle River Magdalena; Porce-Nechi; and middle and lower Rivers Atrato / Carribean basins. The topography of Antioquia lends itself to a “special wealth for hydroelectric production” – which then translates to the potential for the largest reserves of water in Colombia. A report “Actualización del Estado del Arte del Recurso Hídrico en Antioquia” (translated “Status

Update of Water Resources of Antioquia") warns about the lack of awareness of water supply, the quality of water and social problems caused by lack of access to potable water. The report further states that there are abundant and sufficient water supplies to meet consumption needs (Centro de Ciencia y Tecnología de Antioquia - CTA, 2013). However it can be concluded that there remains a major challenge to curb water pollution and contamination, and to continue with infrastructure development to ensure that all the population has access to potable water and sanitation.

### 3.5.1 The opportunity for innovative solutions for Antioquia and Colombia

Colombia is ranked above the median in the Global Innovative Index, and Medellin has been ranked extremely high in the global perspective for its innovation. In section 3.2 above, it has been noted that Colombia is in the process of establishing a strong research and development foundation in the field of nanotechnology by creating research groups, networks and research centres.

Growing population and increased urbanisation creates a high demand on conventional water supplies and unconventional water sources (eg. stormwater, contaminated water, wastewater and seawater). Nanotechnology based water treatment alternatives could provide new capabilities to treat unconventional water supplies to supplement existing, conventional water supplies and to overcome the gap between demand and supply. Current and potential applications for water and wastewater treatment are numerous and include, for example (Qu, Alvarez & Li, 2013):

- Carbon based and/or metal based nano-absorbents
- Nanocomposite membranes and thin film nanocomposite membranes
- Forward osmosis
- Reverse Osmosis

- Photocatalysis, amongst others

The needs of Antioquia for the provision of potable water and decontamination of water supplies are an imperative. Medellin needs to capitalise on its reputation for innovation by calling for effective solutions that are not only cost-effective, but also extremely timely in implementing them. For example, it could take 3-5 years to provide the aqueduct demanded by residents of Granizal, Bello. On the other hand, it could take less time to devise and deploy a solution, temporary or permanent eg. based on nanotechnology filtering systems which could prevent health hazards and diseases in the short term.

Antioquia could refine and redefine legislation, train and educate the population, maintain existing and deploy new water treatment plants and the like to help curb water pollution and conserve its vital natural water supplies.

In addition, Antioquia could set the pace for itself and for Colombia by implementing some of the many innovative technologies for example (but not limited to):

- **Nanotechnology in filtration**: Researchers in India have developed a technology that uses composite nanotparticles which emit silver ions that destroy bacteria and other contaminants from water. Researchers at the Indian Institute of Technology Madras in Chennai, India, have developed this purification device that filters microbes, bacteria and viruses, and chemicals such as arsenic, lead and pesticides from water (Chow, 2013) (see figure 19). According to the developers, the filtration process takes approximately an hour, and current prototype containers hold up to ten litres of water. They are currently trialling the devices in rural communities of India and claim this would shortly be commercially scalable and could cost as little as $2.50 per year to deliver safe water for a family.

**Figure 19**

**Prototype of Water Purification System Being Trialled in India**

Source: (Thalappil Pradeep – Indian Institute of Technology Madras in Chennai, India Chow, 2013)

- **Membrane chemistry**: Membranes with pores which could be 10 or 20 nanometres across (3,000 times finer than human hair) which could be used for water treatment processing. Membrane technology has been used for several years in water purification, and it is reported that recent breakthroughs have resulted in reducing the cost of desalinated water from $1 per cubic metre to between $0.50 and $0.80 (Henley, 2015)

- **Seawater desalination**: Use of a process which uses reverse osmosis, in which seawater is forced under pressure through a membrane that strips out the salt (Gomall, 2015). This technology is costly and consumes around 4 kilowatt hours of energy. More recently, National University of Singapore has engineered new technology (mimicking the mangrove plant) in the form of biomimetic membranes enhanced with aquaporin: proteins embedded in cell membranes that block out salts. It is claimed that this low pressure innovation could reduce wáter purification costs by 30% (Asian Scientist Magazine 2015). Other compact desalination plants are currently being developed and implemented in many parts of the world (Henley, 2015). See figure 20.

**Figure 20**

**A GE Power Compact Seawater Reverse Osmosis Desalination Plant**

Source: General Electric www.gewater.com

- **Photo-chemical process:** New Oregon based company Puralytics has developed a system that uses light to actívate five photochemical processes in a nanotechnology mesh which draw contaminants into the mesh, break them apart at molecular level and filter out clean wáter. Products include a solar bag filter and a solid state wáter purifier which can produce up to 4000 litres of clean water per day (CNBC, 2015).

- **Smart monitoring**: New monitoring technologies such as pressure and acoustic sensors enable smart monitoring to detect and prevent leaks and pollutants from entering in the water supply networks. It is claimed that in developing countries alone, approximately 45 million cubic metres of water are lost every day in the distribution pipelines (Henley, 2015).

- **Wastewater processing**: Designing of wastewater treatment plants that are more compact which can be used for small scale rural community requirements. See figure 21 below, which could be a typical efficient and economic solution for rural areas that currently lack sanitation and wastewater plants. Ashbourne was the first town in Europe to install the HYBACS system which can process over 40 percent more waste at a low cost and minimum carbon emissions (Ashbourne News Telegraph, 2012).

**Figure 21**

**The HYBACS system**

Source: image - Bluewater Bio

- **Mobile water recycling facilities**: Use of mobile nanotechnology based filtering units could address problems such as the one reported recently in Caldas, and could also be provided for residents to address problems such as in Granizal as mentioned above. There are various solutions under development, however, Antioquia could commit to optimise solutions for local requirements and emergencies.

# 4. CONCLUSION

Colombia is one of the most bio-diverse countries and one of the few countries which have been blessed with abundant water in Latin America. The country has also experienced strong economic growth in recent years.

Colombia has many challenges to overcome with the contamination of its water supplies, climate change and the supply of potable water - a basic commodity which is becoming more difficult to provide to everyone given regional and global trends of water shortage. There is a need to overcome these challenges before it is too late and the problem becomes aggravated and unsurmountable, which has the danger of affecting the environment, the economy and the quality of life of its habitants.

Nanotechnology presents great potential to revolutionize water treatment and purification to remedy and prevent water scarcity with solutions that could be more timely and cost-effective. Nanomaterials possess unique properties and potential such as high surface-to-volume ratio, high reactivity and sensitivity, high absorption and can form films on substrate, to name a few (Bora & Dutta, 2014). By treating water from unconventional supplies and by effective treatment of wastewater, the gap between demand for clean / potable water and supply of water can be bridged.

In the previous section, various examples are cited in the science of nanotechnology for the provision of clean water – these are but a few notable advances, with the potential for more innovations and exploitation through further research and development. Whilst Colombia needs to focus on water conservation and to curb pollution of its natural water resources, the country has the opportunity to also focus on the use of nanotechnology for:

- Discovery and identification of potential applications for the conservation and presevation of valuable water resources;
- Remediation of damage, eg. to water supplies and the environment; and
- Decontamination of polluted water and wastewater for recycling and reuse in other areas eg. agriculture and industrial uses.

It is therefore recommended that Colombia embraces and boosts investment in R&D in the field of nanotechnology, particularly in technologies for water treatment and purification.

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