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Renewable energy integrated desalination: A sustainable solution to overcome future fresh-water scarcity in India

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ABSTRACT

Fossil fuels such as coal, petroleum, and natural gas have been used as the major sources of energy in the recent past. However, the negative environmental impacts associated with the emission of the greenhouse gases from these conventional energy sources forced to realize the importance of renewable energy resources. At the same time, the average annual exponential rate of population growth in India needs increasing amounts of fresh-water for the basic necessities. This might result in water scarcity as the overall population in India is expected to increase to 1.60 billion by 2050. It has been forecasted that, by the year 2040, India will rank 40th in the world in terms of water scarcity. To meet the rising fresh-water demand, desalination is an intelligent and sustainable option for India, which has a very long coastline measuring 7517 km. In this paper, an attempt has been made to provide a comprehensive review of water scarcity in India and suggest a possible solution, which is implementing desalination technologies coupled with renewable resources. The paper reviews the ground water scenario in India and the global desalination market. We summarize the energy consumption in various desalination processes and provide a brief outlook of the desalination techniques in India. Apart from this, desalination using non-conventional sources such as solar, wind, and geothermal energy is discussed. In addition, factors affecting the environment due to desalination and the potential counter measures are presented. This review aims to provide an awareness of the projected water crisis in India, in the coming decades, and is also aimed to help the policy makers for selecting an appropriate desalination technology.

1. Introduction

Water, which is available on the surface as well as underneath the earth, is the fundamental resource that doesn't have any substitute for its numerous applications such as drinking, irrigation, domestic uses, generation of hydroelectricity, and industrial uses. According to the United States Geological Survey (USGS), nearly 97% of water is present in the oceans, which are saline in nature and the remaining 3% of water is fresh. The fresh-water is distributed amongst icecaps and glaciers in Arctic and Antarctic region (68.7%), surface water (0.3%) and ground water (30.1%). Out of surface water, 87% is contained in lakes and rest in rivers and swamps [1], which means that only 1% of total water found on earth is usable by human beings. Water being the foundation of life, the scarcity of it is currently affecting one fifth of the world's population and a quarter of world population face shortage of technology to retrieve fresh-water from rivers and ponds [2]. This scarcity of water is a serious problem which is an after effect of increase in population and development in industrial and agricultural sectors. The United Nations World Water Development Report released in 2015 forecasts that there will be 40% shortage of drinking water in the world by 2030, which is only 14 years from now [3]. This projected water shortage and scarcity can be overcome by sustainable use of water along with suitable techniques for treating waste water as well as obtaining fresh water. In order to add fresh-water stocks to that existing presently, the only possible way is to purify the highly saline ocean waters that comprises 97% of the total water present in this earth [1]. Coming to India, it is forecasted that it will rank 40th in the world by 2040 in terms of water scarcity [4]. However, the presence of a long coastline in India measuring 7517 km [5] gives an added advantage to use the desalination technique to overcome the projected water scarcity.

The concentration of salt in fresh-water and seawater varies from 500 ppm (ppm) to 35,000 ppm [6]. According to the World Health Organization (WHO) report, excess concentration of chloride levels of about 0.25 kg/m^3 and sodium levels of 0.20 kg/m^3 in drinking water results in detectable taste in water [7]. In order to increase the fresh-water quantity to meet their basic needs, humans have practiced various forms of purification technologies on sea and brackish waters

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since long. This process, which is called as desalination, is an attractive way to tackle the water shortage problem, as it is the only inexhaustible source of water available in the globe [8].

The process of desalination (to separate minerals from sea water) requires sufficient quantities of energy mainly supplied from conventional fuels and hence becomes costlier compared to obtaining surface and ground water by various methods. Installation of a desalination plant in developing countries is challenging because of huge costs involved towards initial investments, its operation and maintenance. The Middle East countries have abundant conventional fuel resources and hence the local government encourages desalination technology. It is well known that 70% of world's desalination plants are located in the Middle East region [9]. The more desalination is used, the costlier the process becomes as it requires higher energy for separating the salts. The huge consumption of energy in desalination results in greater emission of greenhouse gases, a concern for environmental pollution. An estimate shows that to produce 1 m^3 of fresh-water from sea water, the plant consumes 3–10 kWh of energy where as a conventional drinking water plant consumes 1 kWh/m^3 [10]. In spite of the drawbacks associated with desalination plants, which are mentioned above, it is a sustainable solution to the global fresh-water shortage.

The paper provides a review of various desalination technologies using renewable energy, as an intelligent solution to overcome the water crisis. In this paper, first we discuss about the water trends and future challenges in India. The global desalination market, energy consumption in the desalination processes is described next. Then, the subsequent section explains about the status of desalination in India starting from the sixties till present. In the next section, different desalination process using renewable sources such as solar, geothermal, wind as well as wave energies are mentioned. Then, the renewable energy potential of India is described keeping in mind that these would help in the desalination process in India. Finally, the environmental impacts of desalination in general followed by conclusions are mentioned in this paper.

2. Climate and topography of India

India is the seventh largest and the second most populous country in the world with a total area of 32,87,590 km^2 [11]. India lies in the northern portion of Indo-Australian plate and north of equator between 8°4′ and 37°6′ north latitude and 68°7′ and 97°25' east longitude. The northern portion of India is bounded by the mighty Himalayan Mountains bordering countries with China, Bhutan and Nepal [12]. Pakistan lies in the west and the north east side is bordered with Burma by China and Kachin hills. India is bordered by Bangladesh on east with Khasi and Mizo Hills. In addition, India is bounded by water masses in three sides having a long coast line [13]. The ten major rivers (Narmada, Tapti, Godavari, Krishna, Mahanadi, Cauvery, Pennar, Brahmani, Mahi and Sabarmati) flowing in India are the primary source of fresh-water for the people of India. These rivers finally pour their water in to Bay of Bengal, and Arabian Sea [14].

The climate in India varies from tropical monsoon climate in the south to temperate climate in the north with four seasons: summer, winter, monsoon, and a post-monsoon period. Himalayas, the world's largest mountain ranges which separates Indo-Gangetic plain from Tibetan plateau protects from cold Serbian winds coming to India [15]. The monthly average winter air temperature varies drastically from −40 °C at Kashmir in the north to 27 °C at Thiruvananthapuram in the south. Similarly, during the summer months, there is a huge difference in temperature of around 35 °C between Kashmir and the deserts of Rajasthan in the North West [16]. The north eastern part of India, nestled in Himalayas consisting of seven states, is unique from rest of India and is abundant in natural resources. This region receives 2450 mm of rainfall with a mean temperature of 15–32 °C in summer and 0–26 °C during winter [17]. The western part of the country is occupied by the Thar Desert, a hot arid region of rolling sand hills characterized by low rainfall, extreme temperature conditions, which is greater than 45 °C and high summer winds [18]. The point we want to make here is that the amount of precipitation and its subsequent storage is not uniform throughout India because of its vastness and varied topographical features.

The country's lengthy coast line bordering nine states and four Union Territories meets the Indian Ocean on the south, the Arabian Sea on southwest and Bay of Bengal on southeast [5]. Out of these coastal states, Gujarat, Tamil Nadu, Andhra Pradesh, Kerala and Karnataka are facing higher water scarcity due to lower ground water level and higher demand. With depleting water resources, supplementary supply is essential to meet the day to day requirements of the people. Taking advantage of the oceans bordering the country, desalination could be a future sustainable solution to meet the fresh water needs for millions of people living in India.

3. Drinking water trends and future challenges in India

The exponential increase in population has led to stress in water resources in the country, which is mainly a man-made problem. The main source of fresh-water supply to the country is from the surface and ground water. During monsoons, India gets nearly 75% of total annual rainfall of which 48% represents surface water. The whole of India receives less than 4000 billion cubic meters (bcm) of rainfall annually, which also includes snowfall [19]. The annual average rainfall varies across the states with 544.8 mm in north western parts to more than 2072.8 mm in north eastern part of the country [20]. In addition to the rapid increase in population, the climate change also introduces additional-stress to the hydrological cycle and alters the water resources systems. The over exploitation of water resources, and increased pollution has led to scarcity of fresh-water resources across the country. According to Central Water Commission's (CWC) annual report (2013–2014), the water resource potential of the country is estimated to be 1869 bcm considering both surface and ground water [21]. In India, ground water is the main source of water in rural and urban areas which is replenished from precipitation and river drainage. A report published by the Central Ground Water Board (CGWB) on November 2014 describes about the ground water level in India based on a survey of 14,904 wells. It was found by CGWB that 20% wells were showing water level less than 2 m below ground level (m bgl), 39% showed depth range of 2–5 m bgl, 26% showed water level in the range of 5–10 m bgl, 11% showed 10–20 m bgl, 3% in the range of 20–40 m bgl and 1% more than 40 m bgl [22].

In India, ground water contributes, 85% for drinking, 60% for agriculture and 50% for urban requirements. The estimated total utilizable water in the country is about 1123 bcm of which, surface water constitutes 690 bcm and ground water constitutes 433 bcm. By the year 2050, there will be an estimated necessity of 1450 bcm water, which would create a deficiency of 327 bcm of water for the population of India by 2050 [19]. Due to population rise and developments in India, nearly 688 bcm of water was utilized for irrigation in 2010 and 1072 bcm of water will be utilized in 2050 [19]. According to a new report by World Resource Institute (WRI), the most populous countries, China, India, and the United States of America (USA), are presently under high water stress of 40–80%[4]. In the northern part of India Tiwari et al. [23] examined the groundwater depletion rate, which was estimated to be 54 ± 9 Gt/yr over the period April 2002 to June 2008. This large ground water decrease was attributed to the imbalance between exploitation and replenishment [23]. As a result, excessive lowering of the ground water table has made pumping more expensive and many wells have insufficient water to meet the necessity of the people. India occupies 16% of world population and 4% of world renewable water resources. As there is constraint in water resources, its per capita availability also reduces with population growth. As shown in Table 1 [24], the per capita water availability in 1951 was 5177 m^3/year when the total population was 361 million. In 2001, when the

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