ISSN 0126-2807

Journal of Applied Sciences in Environmental Sanitation

Volume 4, Number 2: 151-166, May-August, 2009

Review Paper

LONG TERM CONSEQUENCES OF GROUNDWATER PUMPING IN AUSTRALIA: A REVIEW OF IMPACTS AROUND THE GLOBE

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Received: 23rd July 2009; Revised: 26th August 2009; Accepted: 31st August 2009

Abstract: Groundwater or subsurface water refers to all water below the surface of the ground including that in the saturated zone and in deep aquifers. Subsurface water has been a readily available source for humans over centuries and has been particularly associated with developing nations. This source has in the past been ill managed and has caused water quality issues in many communities around the world. In recent times, serious drought conditions have affected the vast Australian Island continent and government authorities have considered pumping large amounts of groundwater for drinking use in many states; that is, pumping groundwater for inclusion in the direct supply networks. This paper explores the effects of longer term pumping; in particular various issues related to the excessive groundwater pumping. The review shows that majority of the affected areas are coastal lowlands where most of the world's population reside. Long term effects that warrant serious attention are saltwater intrusion, aquifer overdraft, groundwater depletion, land subsidence. Each of these has had severe consequences for the areas concerned and indeed some more the others. However, in the past, the most reported has been saltwater intrusion at the expense of the others.

Keywords: Groundwater use, ground water pumping, longer term effects, consequences of pumping

INTRODUCTION

Groundwater is an important hidden resource for water use [1]. Subsurface water resources have been particularly utilized in the areas of low rainfall and alluvial low land coastal plains [2]. In the drier and more inland parts of the world, groundwater is also a major source of fresh water available for agriculture, mining including other domestic activities apart from human consumption. In many parts of the world mentioned in the paper, the population of the regions rely on groundwater supplies since surface water resources such as lakes and rivers are scarce [3]. In most cases, the subsurface water is brought to the surface using pumps specially made for various aquifer systems or conditions. High yielding aquifers, lower yielding aquifers and reticulated air systems are three types of pumping systems used most often [4].

Pumping of groundwater solves many immediate problems faced by those living in lowly developed and low rainfall regions but there have been many negative effects pumping such as pollution of aquifers, seawater intrusion and so on. Coastal regions including those in Australia have experienced saltwater intrusion into coastal aquifers resulting significant deterioration of the subsurface water quality [5-7]. Sea water intrusion is important issue and appears to be of main concern in the literature but the problem may be more severe in arid and semi-arid regions where the groundwater constitutes the main freshwater resource [8]. Excessive pumping has led to other long term effects that have been less reported. As this review suggests, there are other longer term critical effects that have been not so well reported and one of the aims of this paper is to highlight other equally important long term effects of pumping from groundwater.

Possible effects of climate change have been reported widely in the general literature and there is no reason to believe that climate change will not influence subsurface conditions such as groundwater levels. In fact some literature already exists that suggests groundwater will be seriously influenced [9, 10]. The uncertainty of future conditions makes this an appropriate juncture to examine the existing literature and identify longer term effects of groundwater pumping. Such a review will provide important implications for countries such as Australia, where groundwater has only recently being more relied upon for domestic and household use.

The main aim of this paper is to identify the longer term consequences of groundwater pumping generally and then consider the implications for drought prone regions of the world such as Queensland, Australia.

GROUNDWATER PUMPING

Pumping of groundwater requires much investment by authorities but more critically, it requires well informed planning such as where the bores are to be situated and how they are to be constructed. Construction costs are raising over time due to market forces but the construction is itself problematic for the bore has to be sustainably built for long term use and maintained over time in satisfactory working order. Indeed, feasibility studies are needed and are to be done well before the bore construction, to understand the aquifer condition, water quality and any disposal options. The ignoring of the initial planning and construction can lead to difficulties in terms of long term consequences [4]. Figure 1 shows the typical pumping bore showing the initial water level and the flow changes in dry conditions around the bore.

As mentioned earlier, coastal seawater intrusion has been reported widely and is an important world concern. The following section briefly reviews seawater intrusion and the long terms effects of pumping in coastal areas. Other equally important issues such as aquifer overdraft, groundwater depletion and land subsidence are discussed in the following sections.

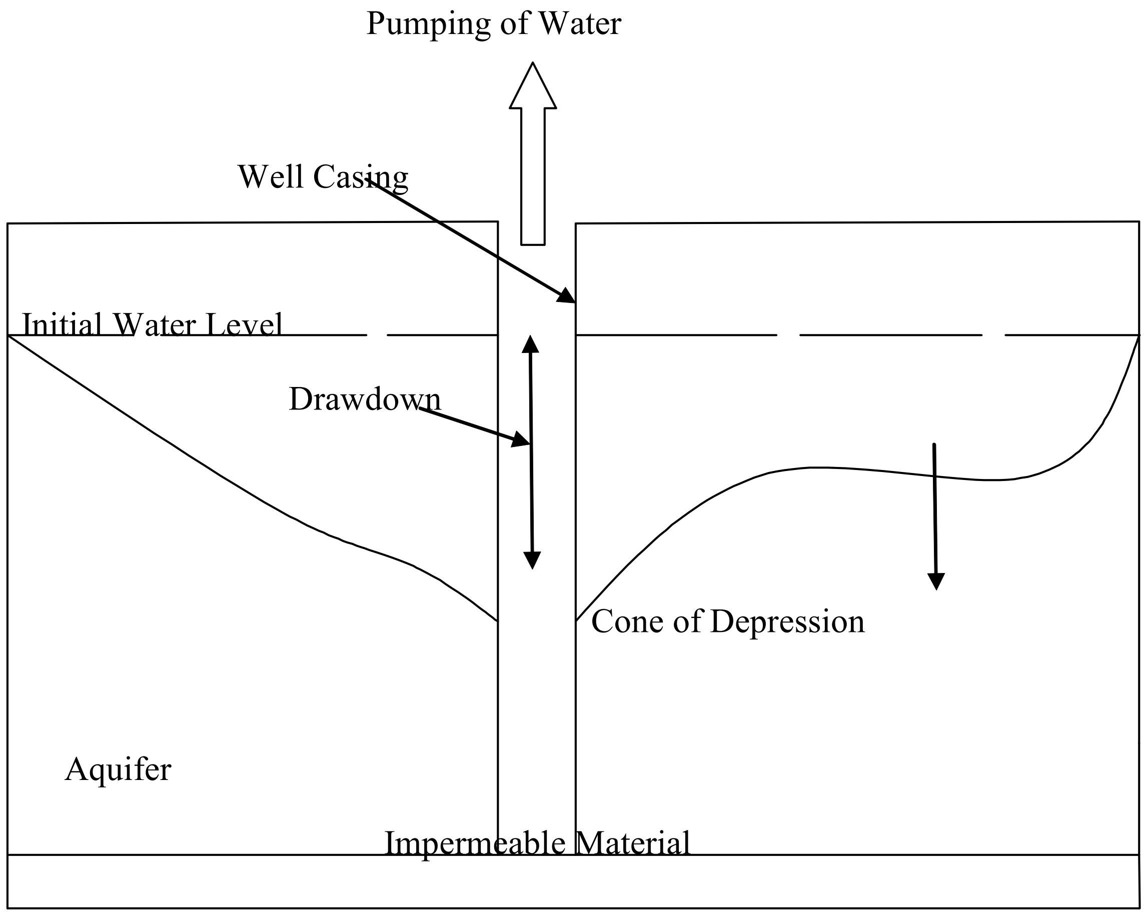

Fig. 1: A typical groundwater pumping bore.

SEAWATER INTRUSION

Seawater intrusion is the movement of saline water into fresh water aquifers in coastal areas often due to human activities such as irrigation (see Figure 2) [11]. Saline water intrusion is not only caused by decrease in groundwater levels but also by rises in seawater levels that is real concern for future generations. The present concern however relates to groundwater pumping that is usually required for irrigation purposes. The pumping levels are often high enough to cause sea water to invade fresher water aquifers [5, 12]. Contamination of coastal aquifers by seawater is generally due to pumping above the safe yield capacity and the effect is more severe when pumping closer to shorelines [13-16]. In fact, seawater intrusion is the consequence of overexploiting coastal freshwater aquifers [14, 16, 17].

There are many studies that have shown that saline intrusion occurs all around the world. Shing-Ma [18] conducted analysis of water samples in Great Bend Prairie freshwater alluvial aquifer in South-Central Kansas (US). He reported that landward movement of the saltwater was due to continuous extraction of fresher water from this aquifer. Benavente [17] reported that Mediterranean and South-Atlantic coastlines (Spain) are affected by seawater intrusion. He argued that seawater intrusion caused by pumping is one of the main causes of groundwater pollution. Other countries such as Israel, Mexico, Chile, Peru and Australia are also affected by seawater intrusion.

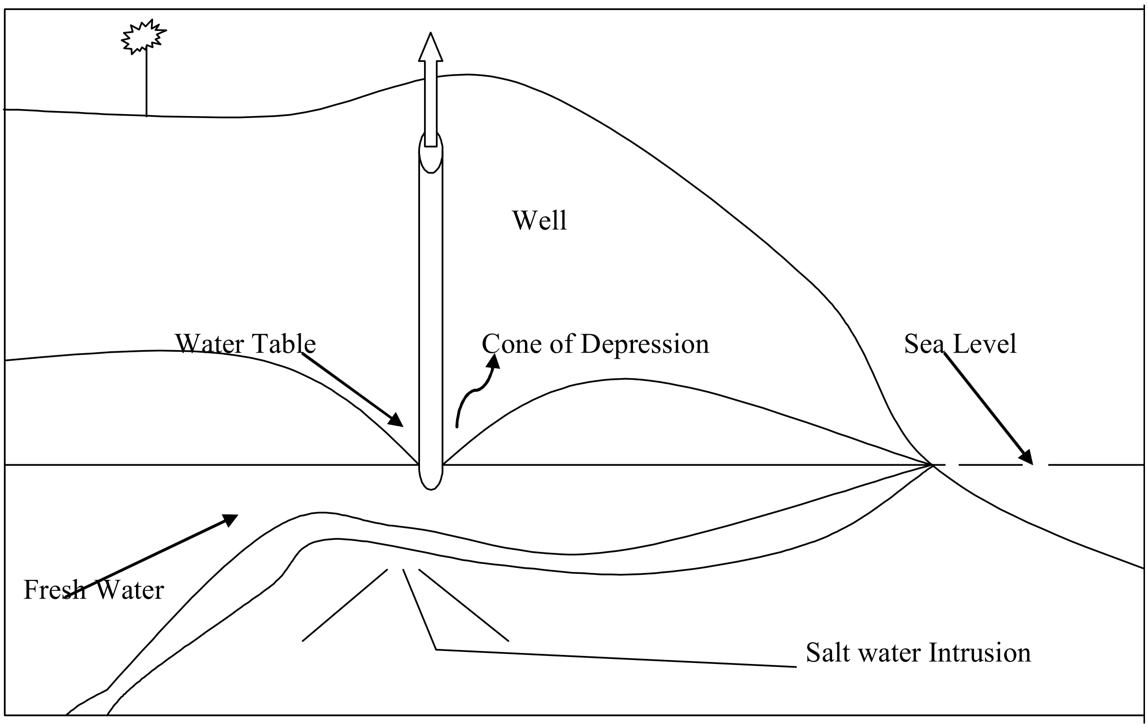

Fig. 2: Seawater Intrusion

Seawater intrusion effects

In general, groundwater flow through an aquifer can be determined through distribution of hydraulic heads. The decrease in hydraulic head would allow the entry of salt water from oceans thus mixing with freshwater leading to saltwater intrusion [19, 20]. In Florida (US), Dennehy [19] found that hydraulic head of an aquifer was decreased by excessive pumping. In some extreme cases saltwater intrusion has polluted supply wells close by but pumping over time also decreased the amount of fresher water storage in the aquifers generally.

Exploitation of groundwater resources for agricultural purposes has lowered the water table in coastal Spain causing seawater intrusion [5, 14]. Similar type of groundwater quality degradation was observed in Kiti aquifer in Southern Cyprus [21]. The quality of groundwater aquifers can also be adversely affected by pumping if interlink connections exists between brackish or saline water [1, 22, 23]. Evans [16] reported that many coastal aquifers along the Mediterranean Sea (particularly during the tourist season) are affected by seawater intrusion due to lowering of water tables caused by exploitation of groundwater basins. As a result, countries such as Cyprus and Israel have shut down hundreds of wells along the coastlines that were used primarily for drinking water due to this problem [16].

Large portions of Washington's coastal aquifers are unusable because of seawater intrusion. This is particularly the case in coastal areas where the population growth is high and thus large amounts groundwater supplies are being used. In most cases, seawater contains 19,000 milligrams of chloride per litre (mg/l) while freshwater generally contains less than 30 mg/l. Humans notice a salty taste as soon as the chloride concentrations in drinking water exceeds 250mg/l [5, 17, 24].

Seawater intrusion pollutes water that humans consume thus leading to aesthetic and health issues. The excess quantity of salt in drinking water is an aesthetic concern because salty tasting water is unpalatable for most people. The health issues are also a concern in seawater intruded areas, particularly for those people on salt restricted diets [5, 17, 24]. Human consumption of subsurface water containing high concentration of sodium ions contributes to heart diseases or even high blood pressure [5, 6, 8].

In the Cornia basin (Italy), boron leaching from sediments to local groundwater has been attributed to seawater intrusion. The intruding water has facilitated the release of boron from clay minerals (Vengosh, 2004). Vengosh reported that water-rock interaction is the main mechanism for the boron enrichment making the water unsuitable for human consumption. Grassi [12] analysed goundwater samples in Cecina (Italy) and attributed the decline in the drinking water quality to seawater intrusion.

The utilisation of such water will not only lead to aesthetic and health problems but its use also causes agricultural and environmental problems. Intrusion is a concern to those using groundwater for agricultural purposes since salty water damages plants and shrubs. Moreover salt intruded can also have detrimental effects on wetlands and estuaries (see later) of our coastal environments where smaller communities may be sensitive to salt levels [16, 22, 24, 25].

Indeed, saltwater intrusion will be a critical issue in future for Australia due to the large coastlines where majority of the population reside [6]. It is then of critical importance to understand the effects of varying recharge and groundwater pumping on the movement of saltwater to avoid such environmental disasters in future [1, 6].

The groundwater quality is deteriorated not only via intrusion of sea water but also caused by the existence or release of various toxic elements as noted earlier.

Water Quality Issues

Water quality refers to the amount of dissolved solids and biological pollutants in solution [5]. The quality of ground water is determined by the chemical properties of precipitation, the mineralogy of soils and aquifer materials through which the water moves, and the length of time the water has been in contact with these soil and aquifer materials. The quality of ground water is a primary concern where ground-water resources are used for public and domestic supply. The water quality deteriorates by the introduction of contaminants into the environment through human or natural activities. The most significant diffuse contaminant of groundwater in Australia is nitrates, due to their adverse affects on people, animals and the environment. Chemicals enter the environment either from point or nonpoint sources. Pollutants from point sources are generally related to urban development, while diffuse sources are generally rural in nature. Some significant point-source contaminants include underground storage tanks (hydrocarbons), landfills, intensive rural industries (nitrate), cattle and sheep dips (pesticides), manufacturing spills, and mining-related activities (heavy metals, acid, hydrocarbons). Non-point sources of contaminants include widespread application of fertilizers and pesticides in agricultural areas and emissions from automobiles in urban areas [26].

Increasing exploitation of groundwater for domestic and industrial use has also occurred in the Bengal Basin (India). The water has been pumped from deeper fluvio deltaic aquifer that contains high concentrations of arsenic [7, 27]. According to Glennon [22], higher temperatures in lower ground levels facilitate in dissolving elements such as arsenic, fluoride and radon that are more prevalent at deeper levels.

In the coastal area of Yui-Lin (Taiwan), the over extraction of groundwater has been the major cause of arsenic pollution. Liu [13] reported that extraction of groundwater introduces excess dissolved oxygen that in turn oxidizes the orginal immobile minerals, releasing arsenic ions (by reductive dissolution of arsenic rich iron oxyhydroxides). The consumption of such contaminated water leads to the well known disease called "Black Foot". This disease has also been reported in Southern parts of India and Bangladesh.

In Mexico, Raquela [23] reported that subsurface water pumped from well fertilized agricultural lands contain inappropriate levels of toxic materials. It seems that the materials have accumulated over a long period of time. Chirenjea [28] reported similar findings from his analysis of the Kirkwood Cohansey Aquifer System in New Jersey (US).

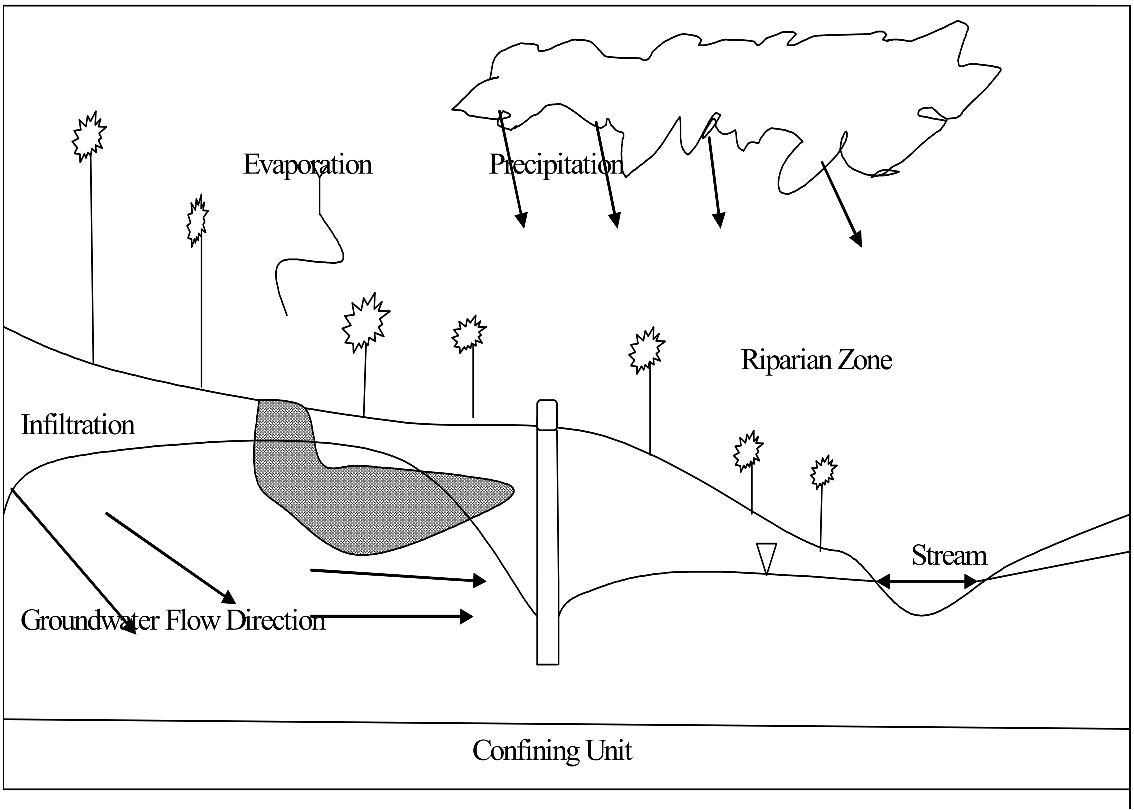

Fig. 3: Pollution of groundwater

Seawater intrusion is found to be one of most important problem associated with pumping and water quality. Another issue related to excessive pumping is aquifer overdraft. The impact of aquifer overdraft may be less compared to that of saltwater intrusion but it is an equally important consideration. Salt water intrusion occurs near coastal aquifers whereas aquifer overdraft occurs closer to the pumping areas.

AQUIFER OVERDRAFT

The scarcity of recharge and groundwater is a primary cause of overdraft. Overdraft is defined as pumping of water from an aquifer in excess of the supply flowing into the basin. If continued this results in depletion of groundwater that can irreversibly harm the environment. One of the consequences is subsidence or sinking of the land but his is discussed later. The slow natural recharge rate of most aquifers and high rate of pumping has led to groundwater overdrafts in many irrigated regions of the US. Schmidt [29] reported that a number of California's aquifers are now in overdraft conditions.

Zektser [30] reported that long term groundwater extraction exceeding the aquifer recharge has led to overdraft problems in South Western United States. This region is one of the driest place in North America continent. In the semi-arid region, the large demand for usable water has led to groundwater overdraft in many aquifers.

The Alto Rio Lerma Irrigation District (Guanajuato, Mexico) is an agricultural area and its sustainability depends partially upon groundwater withdrawal for crop irrigation. Because of high pumping demands and current land-management practices, groundwater levels have declined severely resulting in aquifer overdraft [31]. The short period of rainfall in this area, combined with high groundwater withdrawals from irrigation wells has produced aquifer overdraft. Negative environmental impacts include continued diminishment of groundwater quality and declining groundwater levels in the basin, that in turn damage surface water systems that support environmental habitats close to the area [23].

In North West China, the groundwater level has been steadily decreasing because of pumping and a decrease in recharge levels. He attributed the decline in water levels to aquifer overdraft. China, India and Mexico are some of the largest users of groundwater in the world and all facing critical overdraft challenges, where pumping exceeds aquifer recharge. India and Mexico have instituted regulatory measures to reduce groundwater overdraft [32].

Groundwaters levels have been declining due to high water demand in Arusha (Tanzania, South Africa). Some of the impacts of groundwater overdraft are higher pumping costs, land subsidence, depletion of surface water and degraded aquifer water quality [33]. Ongor [34] stated that many of the African countries are most vulnerable to overdraft problems. Although critically vulnerable, there is much less research literature on groundwater use and its long term effects throughout the African continent generally.

GROUNDWATER DEPLETION

Depletion of groundwater levels is a global phenomenon and is another issue associated with subsurface water pumping in many countries [3, 35]. Depletion of the groundwater level is defined as long term water level declination caused by sustained groundwater pumping over time [3]. Sustainable water use in the Piedmont region of the Taihang Mountains (North China Plain) is under serious crisis due to the rapid depletion of groundwater caused by pumping [36]. Groundwater depletion has affected major regions of the Middle East, South and Central Asia, North China, North America, Australia [37].

In the US, the Great Plains (Ogallala Aquifer) is a prime example where groundwater depletion has been noted. This aquifer provides water for South Dakota, Nebraska, Colorado, Wyoming, Kansas, Oklahoma, Texas, and New Mexico. It spans an area of 800 miles from north to south, and 400 hundred miles from east to west. The water pumped from Ogallala Aquifer is used mostly for irrigation purposes [38].

According to Perlman [2] the long term pumping in Chicago has indeed lowered ground water levels affecting the water table significantly. Mexico City was built on an old lake-bed which is surrounded by mountains. It does not have access to a nearby surface water source, thus most rely on underground aquifer for drinking water. This has caused the severe depletion of the aquifer and land subsidence (see later)

Other countries affected by groundwater depletion are India, China and Iran. In some areas of India, the water tables have dropped as much as 70 centimetres (approximately 25 inches). Up to 25% of India's agriculture may be threatened by the depletion of groundwater resources. In areas of northern China, the water table has been dropping overtime at the rate of 1.5 meters a year for the last ten years. Water tables have been drastically reduced all over the world, especially in areas that rely heavily on agriculture for income. Many cities in North Africa, as well as the Middle East, are experiencing harsh water shortages. In Iran, villages are being evacuated because wells are running dry and there is little or no water supply to support the population of the village [38].Groundwater depletion leads to drying of wells, reduced surface water flow, subsidence, and deterioration of water quality [37].

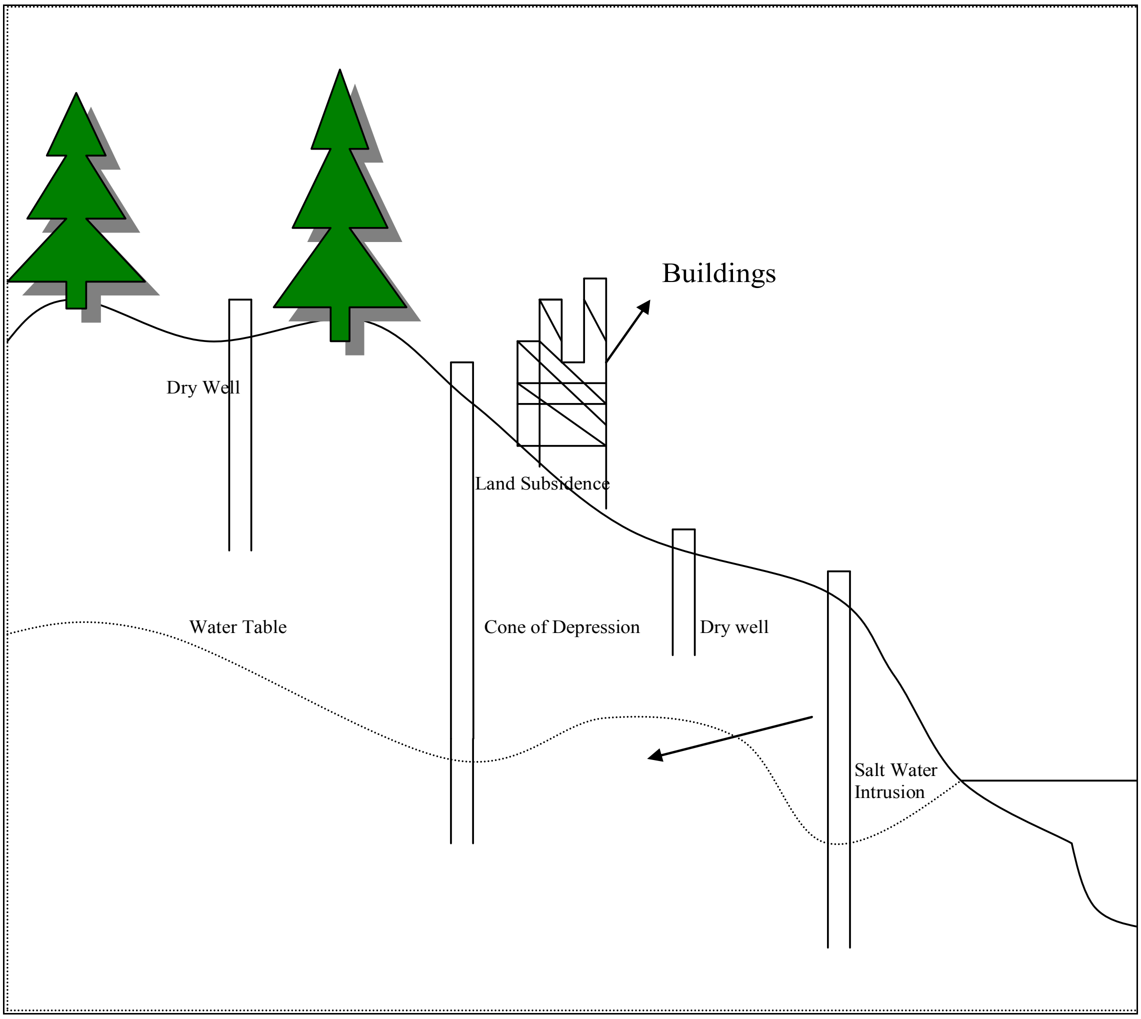

Fig. 4: Impacts of groundwater pumping

Rivers, Lakes, Ponds, Streams

Glennon [39] observed in Florida (US) that rivers, streams, lakes and ponds are vanishing and he attributed this to groundwater depletion (discussed earlier). Pumping over time leads to declining groundwater levels thus affecting the rivers [3, 23, 40]. In Minnesota, US pumping have resulted in lowering of water level affecting the lakes and ponds as noted in the report of field studies by Laura [41]. Glennon [22] and Perlman [2] both reported that groundwater pumping causes water levels to decline overtime and due to this lakes and ponds got vanished in Florida

(US). In Spain, Muñoz-Reinoso [42] has noted from his field investigation and analysis that pumping for cropping and urban supply has affected the ponds. In Fact Rivers, lakes, ponds, streams have been disappearing overtime in Spain. Water flows from the river to the aquifer or vice versa depending on the level of the water table in the aquifer and on the elevation of the river. If the water table is above the elevation of the river, water will flow laterally toward the river and augment the flow in the river. In most regions water flows laterally towards the river but as groundwater pumping lowers the water table, the direction of the flow of water changes towards the aquifer. This is what groundwater pumping appeared to lower down the water table below the Santa Cruz River in US [16, 25, 39]. The above shows that continuous pumping of groundwater from shallow and deeper aquifers has impacts on the nature of the water table as well as the quality of water.

Aquatic and Wildlife

Extraction of groundwater can reduce the amount of water available for fish and wildlife, obstruct fish passage and result in numerous other habitat alterations in florida and Minnesota in US [22, 40, 43]. Groundwater pumping frequently results in significant alterations in aquatic and wetland ecosystems [25, 33, 42].

Subsurface pumping deplete river basins to the point where river reaches regularly and as a result of this rivers have diminished to such low flows that native species often cannot survive. The environment for fish and other aquatic species also may be altered as the stream level lowers [2]. This has occurred in rivers such as the Carmel River (Central Coast) and the Colorado River in the Colorado Desert (US) [43].

Pumping of groundwater tends to lower the water table level, which affect the environment for plants and aquatic species [10, 20]. For example, plants in the riparian zone that grew because of the close proximity of the water table to the land surface may not survive as the depth to water increases [2].

LAND SUBSIDENCE

One of the least reported impact associated with groundwater pumping is land subsidence [44]. According to an Arizona Geological Survey publication “subsidence is the downward movement or sinking of the earth’s surface caused by removal of underlying support” and is occurred in nearly every state of the United States [45]. It is certain that water in an aquifer is under pressure from the weight of soil and water above. If an aquifer is pumped, gradually the water supporting the soil above is removed, affecting the internal structural integrity of the aquifer; this integrity is reduced. In this manner, the land surface begins to settle and compress; such a process called subsidence [33]. Land subsidence is the lowering of the land surface due to changes in subsurface structure [46].

Subsidence causes sudden collapse of the ground to form a depression, or alternatively gradual subsidence or compaction of the surface sediments and soils. Subsidence in south-central Arizona is a major concern because it has been noted in major agricultural and urban areas [46].

Fig. 5: Land affected by subsidence (Arizona, US).

Phoenix and Tucson are located within this area where agricultural production is high. Being an arid region groundwater pumping is required. Long term pumping of groundwater without much recharge has caused the compressing of sediments that in turn has causes the land to settle or subside. I thas been noted that subsidence occurs gradually and spreads over wide areas; Gelt [47] stated that subsidence in Arizona (US) is mainly due to excessive groundwater withdrawal.

Fig. 6: Surface land affected by earth fissures

Earth fissures are also caused by horizontal movement of sediments and tend to occur when high amount of groundwater pumping is done [45]. Subsidence affects the well casings and in fact is often destructive. Well cases tend to collapse under the pressure of subsidence leading to expensive repairs and even the replacement of wells. Urban areas are vulnerable to the effects of subsidence that may damage structures like bridges, highways, electric power lines, underground pipes; that is, urban infrastructure. Cities are often where large population resides, has other important buildings and facilities, and as such the devastating impacts can be high on the longer term. Subsidence can cause damage to railroads, earthen dams, wastewater-treatment facilities and canals [47].

The effects of groundwater pumping and declining water tables are not usually noted by most people since the water table is underground. The water table in various areas of the Arizona state has been affected by land subsidence due to high groundwater withdrawals i.e. exceeding recharge levels. The consequence of dropping watertable has apparently linked to increased occurrence of land subsidence in the state. For example groundwater level has dropped to more than 500 feet in Southwest of Casa Grande near Stanfield located in Arizona [47].

Liu *et al.* [13] reported that pumping due to intense withdrawals from groundwater in excess of recharge has lead to land subsidence in South-Western Kyushu Island of Japan. Land subsidence is not only a severe environmnetal issue but also has other negative effects such as changes in groundwater and surface flow patterns and decline in storage capacity [1, 20, 41].

Land subsidence appears to be linked with the widespread inundation of the unprotected areas in the North, West and Eastern suburban areas of Bangkok. While breakwaters are being constructed their effectiveness may decrease as the land subsidence continues. The studies conclude that land subsidence is linked to increased flood risk, settlement problems of ground and buildings, coastal regression and seawater intrusion into the aquifers and so on. Subsidence is seriously as it causes settlement of buildings and this is an important aspect in design of buildings in Bangkok [11, 48, 49]**.**

Land subsidence causes damage not only to roads, railways, canals, levees but also it can disrupt water conveyance structures, leading to poor drainage and possible flooding. Wingo [31] found that in California (US) many areas have been affected by subsidence. Subsidence events in areas near the coast appear to be directly linked to pumping [46, 50]. However, Leake [45] stated that inland agricultural lands are more vulnerable to subsidence since large quantity of water is being pumped for irrigation. Growing population levels may further increase subsidence events as the need for more groundwater increases, especially in metropolitan areas.

It has been noted that some areas in Mexico City are sinking. This has also been linked to subsidence; subsidence is further damaging the sewer system. In fact this could potentially cause the untreated sewage to mix with the fresh water in the aquifer. It appears that about 95% of the hazardous waste generated is dumped into the municipal sewage system. If such waste mixes with the fresh water in the aquifer it could render the only water supply to the city unusable. The cleanup process of such an event would be slow and expensive [38].

Urban areas are especially vulnerable to the damaging effects of subsidence. Subsidence resulting from groundwater pumping occurs at about the same rate over large areas and can be difficult to detect, so needs to be investigated more to avoid any further instances [46].

Many studies have reported the link between land subsidence and deep well pumping in Asia. Many large cities in Asia including Tokyo, Osaka, Shanghai, Taipei, Jakarta, Calcutta, Manila, and Hanoi have all been affected [11, 48, 49, 51]. Clearly, the least reported aspect of groundwater pumping has been its link with land subsidence and given that areas of the Brisbane

(Australia) has been affected by subsidence issues, it may be that such subsidence is closely linked to historical groundwater pumping for irrigation and everyday use I the area. The area affected by subsidence is a historical settlement and one of the first in Queensland, Australia.

SUMMARY AND CONCLUSIONS

Groundwater refers to all water which is below the surface of the ground including that in the saturated zone and in deep aquifers and is an important hidden resource for water use. In the drier and more inland parts of the world groundwater is the major source of water available for agriculture, mining including other domestic activities apart from human consumption. Pumping of groundwater solves many immediate problems faced by those living in lowly developed and low rainfall regions of the world out but there have been many negative effects of long term pumping such as seawater intrusion, aquifer overdraft, groundwater depletion, land subsidence. It has been noted that most of the world's population residing near the coastal lowlands are affected by seawater intrusion. Authors have been reported various issues associated with this problem all over the world due to pumping but rather less literature exists on other issues associated with pumping. Water quality issues have been discussed in this paper, as it is a primary concern since groundwater resources are being used for public and domestic supply as well. Excessive pumping leads to decrease in a water level that in turn leads to overdraft problems as observed in many parts of the world. Groundwater depletion is a problem that arises mainly due to pumping above the safe yield. The lowering of water levels caused by depletion has severe impacts on nearby lakes, ponds, rivers and streams. The drying of lakes and ponds then affect wetlands and aquatic species. Land subsidence is another issue associated with pumping and is defined as the downward movement or sinking of the earth's surface caused by removal of underlying support. Land subsidence has been noted to be chiefly associated with excessive groundwater withdrawal. Saline water intrusion is caused by decrease in groundwater levels or by rises in seawater levels and is often a problem to the humans living in coastal areas where rates of groundwater pumping are high enough to cause sea water to invade fresher water aquifers. As a result of this saline water mixes up with fresh water aquifers and water gets contaminated. Over pumping near the shores will leads to pollution of water. The use of groundwater leads to aesthetic and health problems but also causes agricultural and environmental problems. The water quality deteriorates not only by the seawater intrusion but also by the introduction of contaminants into the environment through human or natural activities. The most significant diffuse contaminant of groundwater in Australia is nitrates, due to their adverse affects on people, animals and the environment. Pumping from lower water levels facilitates dissolving of elements such as arsenic, fluoride and radon. The quality of groundwater aquifers can also be adversely affected by pumping if interlink connections exists between brackish or saline water. Thus, pumping from highly fertilized land and contaminated land will have impact on humans. Impact of overdraft is less compared to that of saltwater intrusion. Long term pumping also results in other issues like aquifer overdraft, groundwater depletion, and land subsidence in addition to seawater intrusion.

Overdraft is defined as pumping of water from an aquifer in excess of the supply flowing into the basin results in depletion of groundwater and can irreversibly harm the environment. Continued diminishment of groundwater quality and declining groundwater levels are found to be the impacts associated with overdraft in many parts of the world. Overdraft leads to other problems such as depletion of surface water and land subsidence. Groundwater depletion is a global phenomenon and is defined as long term water level declination caused by sustained groundwater pumping over time. Water tables have been drastically reduced all over the world due to groundwater depletion and have a direct impact on those who rely on agriculture. Lowering overtime leads to drying up of wells and decrease in water levels in rivers, lakes, ponds and streams. In fact aquatic and wildlife are also affected by lowering of water levels. Thus continuous pumping of groundwater from shallow and deeper aquifers has impacts on the nature of the water table.

One of the least reported but most far reaching and potentially destructive impact associated with continued groundwater pumping appears to be land subsidence. Continued pumping of groundwater without adequate recharge, leads to compression of the sediments causing the land to settle or subside. The effects of groundwater over-pumping and declining water tables are difficult to envision for many people since they are mostly underground. Various areas of the US are affected by land subsidence due to high groundwater withdrawals i.e. exceeding recharge levels. Land subsidence is not only a severe environmnetal issue but also has other negative effects such as changes in groundwater and surface flow patterns and decline in storage capacity. It causes damage not only to roads, railways, canals, levees but also to public and private buildings and have other impacts such as increased flood risk, settlement problems of ground and buildings.

Seawater intrusion, aquifer overdraft, groundwater depletion, land subsidence are found to be the direct problems associated with groundwater pumping. Saltwater intrusion will be a more critical issue in future for Australia to consider mainly due to the large coastlines where majority of the population reside. Each of these will require extensive geological and hydrological studies to be done in order to predict and protect the environment and human sources from longer term effects. Therefore extensive studies need to be done to predict the impacts of pumping mentioned in this paper particularly in coastal areas where groundwater will be utilized in large amounts in future.

Implications

Extensive feasibility studies at the pumping site need to be done before bore construction, to understand the aquifer condition, water quality and any disposal options. Quality of water continuously is to be monitored. All the pumping levels areas are to be monitored. Effects of pumping on river, lakes, ponds and streams are to be studied. Extensive studies are to done to determine that whether pumping can alter the conditions of a watertable, flow patterns etc. Various effects on wetlands and aquatic species should also be considered while pumping. To protect the land from subsidence, geological information should be gathered before pumping is done and extensive modelling in water over large periods.

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