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Groundwater Distribution in Urban Settlement

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ABSTRACT: Urban cities are noted for technological and economic advancement but are also the convergent localities for poverty, humans' disparity, environmental degradations and the propagation of communicable diseases. This study examined groundwater distribution in urban settlement with a view to identify and proffer solutions to the associated problems of improper distribution of groundwater in such area. Literature search was employed mainly to unravel the various groundwater distribution techniques and inferences were made on how to improve the distribution techniques. The study reveal springs, sunk wells and boreholes as the main methods of groundwater distribution in urban areas. Urban settlement leads to uncontrollable rise in population which adversely affects the quantity and quality of the groundwater. There is a general decrease in quantity due to overexploitation while the quality degraded as a result of pollution from industrial waste and the people. In addition, pollution could be linked to saltwater intrusion since most urban regions of the world are in the coastal area. Groundwater distribution could be ameliorated through recharge management employing artificial recharge. Degraded groundwater quality could be treated to the standard of potable water. Protecting groundwater resources amidst the prevailing rapid urbanization represent a considerable challenge that can lead to escalating costs of provision of drinking water in the areas and cause considerable decrease in public health conditions. Also, as it is technologically difficult and economically expensive to treat a contaminated aquifer, groundwater protection measures must be sought beforehand.

KEYWORDS: Desalinization, Environmental degradation, Groundwater, Population, Urban cities.

1. INTRODUCTION

Rain, ice, and snow water sink into the subsurface to form fresh groundwater. The water is stored within the pore spaces between rocks and particles of soil [1]. World water distribution indicates that 2.5% of it is fresh water out of which the chunk (68.7%) is glaciers and ice caps. Groundwater accounts for about 0.76% of the world's water resources [2].

Groundwater can be in circulation below the earth for many thousands of years but it often escapes to the surface, filling rivers, streams, lakes, ponds, and wetlands. Groundwater may come to the surface as a spring or be pumped from a well. Both ways represent common means of obtaining groundwater to drinking [3]. Fifty percent of water supply for municipal, domestic, and agricultural activities is from groundwater.

Groundwater is but one in all the components of the hydrologic cycle that moves water through the environment. During precipitation (rain and snow), moisture from the atmosphere is transported to the land surface. Aside from the arid areas, the bulk of precipitation runs off the land surface, ending up in streams and rivers and eventually reaching the oceans. Evaporation from the oceans carries water to the atmosphere yet again, restarting the cycle. The portion of precipitation that doesn't get away from the land surface infiltrates into the subsurface. Part of that water evaporates or is obsessed by plants which spread water into the atmosphere. This combined loss of water to the atmosphere is evapotranspiration.

The portion of the water that is still within the ground becomes groundwater and is considered as recharge. Groundwater lies beneath all landscapes within the empty space that exists between soil particles or in cracks in the bedrock. Often, the soil near the surface is unsaturated, meaning that the space between soil particles isn't completely crammed with water. This water slowly percolates downward under gravity control. Eventually, it reaches formation, which is the top of the zone within which the soil is saturated with water (i.e., all space between soils particles is crammed with water). A condition during which there's a water level is termed unconfined, to distinguish them from confined, or artesian, conditions. In confined conditions, groundwater is kept concealed by a capping layer of rock or soil that's too tight to permit water to flow through it easily (a confining bed) [4, 5]. Figure 1 illustrates the concepts of confined and unconfined aquifers and shows that multiple aquifers may lie beneath the land surface. Groundwater exists within the subsurface in geologic formations of various characters. Often, it's useful to differentiate between bedrock formations and unconsolidated formations (also called overburdens). Bedrock is the rock that lies at depth beneath the land’s surface. Some sorts of rock, like sandstone, are made from cemented particles that have openings between them. Others, like granite, have essentially no openings except where there are cracks, called fractures, within the otherwise solid rock. Either of those sorts of rocks can store and transmit groundwater. Although bedrock could also be at the land surface, it's usually deeper and covered by unconsolidated soil and geologic deposits within which the particles aren't cemented together, for example, the sand and gravel that form the bed of a river would be such an unconsolidated formation. The processes forming unconsolidated deposits include flowing water, glaciers, blowing wind, and landslides on mountain slopes. Land filling, digging, and earthmoving by man may create unconsolidated deposits. Quite unlike crystalline bedrock formations, unconsolidated deposits can store and transmit groundwater. Indeed, groundwater used for municipal beverages is often from unconsolidated overburden deposits. Such water is treated by disinfection before usage. Groundwater for other purposes may or may not require treatment.

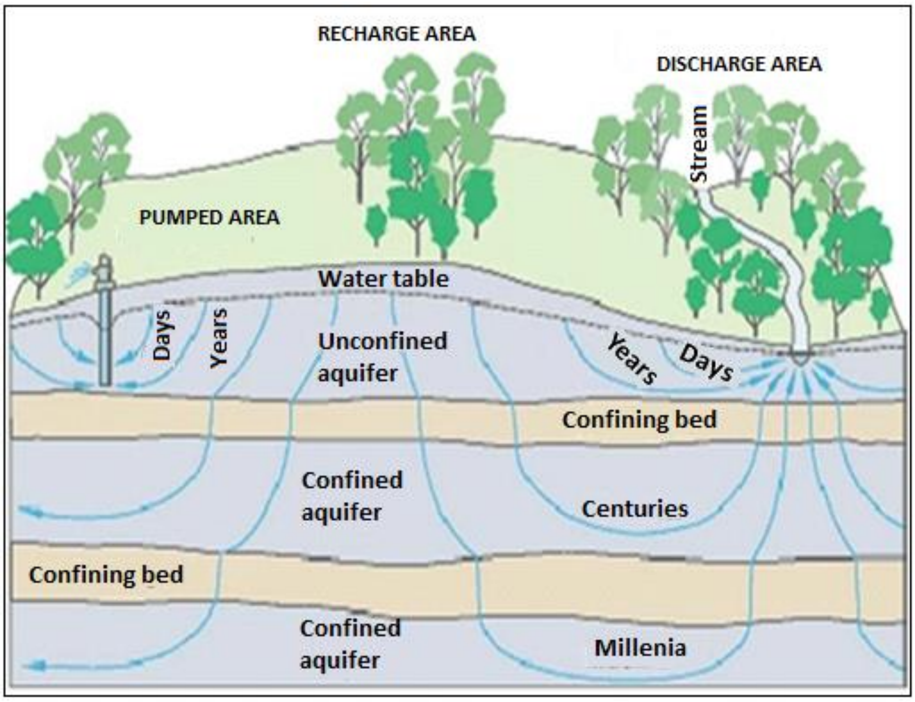

Fig. 1 Illustration of confined and unconfined aquifers and associated travel paths [6]

Treatment of water for agricultural use isn't as demanding as drinking water purposes while water for some specialized industrial activities requires more extensive treatment. Regardless of the use, treatment should be recognized as a viable choice to facilitate the proper use of groundwater. Direct use of shallow hand-dug wells for drinking and other domestic purposes with no form of treatment is widely practiced, especially in the rural, peri-urban, and metropolitan areas of less-developed countries.

For them, the pipe-borne water systems are often difficult for local authorities to supply, hence, shallow groundwater aquifers present the only economically viable water supply option and an affordable alternative [7, 8]. Increasing groundwater supply in Africa is not negotiable since over 300 million people in the continent are still living without access to improved water supply [9]. It is increasingly recognized by many authors [10] that the development of groundwater resources is key to increasing water supply coverage in the region. Furthermore, the protecting the quality of groundwater aquifers becomes imperative in order not to jeopardize public interest especially in these vulnerable communities.

In Nigeria, an estimated 60% of Nigeria’s population gets drinking water from groundwater resources reflecting the resultant effect of infrastructural decay in the potable water supply sector of the country [3]. This situation is aggravated as a result of urbanization in most cities in developing country. People in relatively large number tend to cluster at a particular town especially the state capitals [11]. This study focused on groundwater distribution in urban settlement with emphasis on hand dug wells and boreholes distribution. Problems of urbanization in groundwater distribution are discussed with solutions to such problems proffered.

2. DISTRIBUTION OF GROUNDWATER IN URBAN SETTLEMENT

The two main sources of water supply in the urban settlements are hand dug-wells and boreholes.

2.1. Supply through Wells

A Well is the universal means through which groundwater is obtained for household purposes. A well is a hole or shaft drilled into the subsurface for the purpose of bringing groundwater to the surface. Basically, wells are classified based on methods of construction. A constructed well depends on the subsurface formation and the intended yield. The yield represents how much water can be extracted from an aquifer into a well during pumping. Consolidated rocks serve as aquicludes, aquitards or aquifuges. A crystalline rock such as granite has interlocking crystals without glassy materials and is an aquifuge while other consolidated lithology including slate, sandstone and siltstone may variedly serve as aquicludes or aquitards. Unconsolidated formations (sands, gravel, or saprolite) that lack cementing material often serve as aquifers. On the basis of construction, there are four main types of wells; Bored wells, Driven wells, Jetted wells, and Drilled wells.

2.2. Types of Water Well

(a) Dug Wells

Hand-dug wells are excavations with diameters large enough to accommodate one or more men with shovels digging down to below the water table (Fig. 2). The holes are circular about one meter (m) in diameter and 10 to 30 meters in depth. Some Hand dug wells have been successfully excavated to 60 meters (200 ft). Water and cuttings are removed from the hole using a human-powered bucket-rope-pulley arrangement [12, 13].

Fig. 2. An Example of a Hand dug well

Wells can be lined with laid stones or brick. The linings in most instances are extended upward above the ground surface to prevent contamination and injuries from humans falling into the well. A more recent technique called caisson uses a watertight structure (toughened concrete or plain concrete pre-cast well rings) cased with concrete rings and carefully lowered into the hole. A well-digging team digs below a cutting ring and thus the well's column slowly sinks into the formation, making certain the protection of the team from the collapse of the boring well. Hand-dug wells offer an inexpensive and low-tech way to access groundwater in rural locations in developing countries and could be constructed with a high degree of community participation, or by native entrepreneurs who specialize in hand-dug wells. Hand- dug wells compared to drilling are economical and low tech as they are constructed employing mainly hard labor. Hand-dug wells have low operational and maintenance expenditure, simply because hand bailing can be used in the extraction of water while a pump is required in drilling. Deepening the hand-dug wells becomes necessary especially when the groundwater level drops. Deepen is carried out by extending the liner more down into the formation. The yield of existing hand-dug wells can be enhanced by deepening or through the introduction of vertical tunnels or perforated pipes unto the wells.

Executions of hand-dug wells have numerous drawbacks. It is impracticable to hand dig wells in areas where crystalline rocks are present. Digging hand-dug well in such terrain will be laborious and time-consuming. Most aquifers in crystalline areas are shallow; the well dug in such areas may be prone to yield fluctuations and possible contamination from surface water, as well as waste material. Experts (well-trained personnel) are essential in the construction of hand dug- well. The capital investment for equipment such as concrete ring moulds, heavy lifting equipment, well shaft formwork, motorized dewatering pumps, and fuel that are required in modern drilling techniques may be too expensive for people in developing countries. Execution of hand-dug wells can be hazardous because of the possibility that the well bored can collapse apart from vulnerability to falling objects.

(b) Driven Wells

Driven wells may easily be constructed in unconsolidated material with a "well hole structure", having a hardened drive point and a screen (perforated pipe). The procedure of construction entails hammering the hardened drive point into the ground, usually with a tripod and "driver", with pipe sections added as required. A driver (a weighted pipe) slides over the pipe being driven and is repeatedly dropped on it to facilitate the drilling operation. As soon as groundwater is met, the well is washed of sediment and a pump is installed.

(c) Drilled Wells

Drilled wells are formed using top-head rotary style, table rotary, or cable tool drilling machines. The tool employs drilling stems that turn in the drilled formation, creating a cutting action. However, simple hand drilling methods (augering, sludging, jetting, driving, hand percussion) can be used in the excavation of drilled wells. Drilled wells penetrate deeper into the subsurface and can tap water from much deeper aquifers than dug wells. The depth of drilled wells can often be up to several hundred meters (Fig. 3). Globally, drilled wells with electric pumps are commonly used especially in rural or sparsely populated areas while many urban areas have their water supply somewhat from municipal wells. Most shallow well drilling machines are mounted on big trucks, trailers, or self-propelled vehicle carriages. Water wells usually vary from three to eighteen meters deep, however some areas will go deeper than 900 m. Rotary drilling machines use a segmented steel drilling string, consisting of 6 m sections of galvanized steel conduit that are threaded together, with the drilling bit or other drilling tool at the bottom end. In some rotary drilling machines, a steel casing is designed to be installed by driving or drilling into the well in conjunction with the drilling of the actual borehole. Generally, air and/or water are used as circulation fluid. The function of the circulating fluid is to displace cuttings and cool bits during the drilling [14]. Another form of rotary drilling method (mud rotary), employs a specially made mud, or drilling fluid, which is constantly being altered during the drilling to enable it create enough hydraulic pressure continuously to hold the side walls of the bore-hole open, apart from the presence of a casing in the well. In most drilling instances, boreholes drilled into solid rock are not cased until after the drilling operation, without recourse to the type of machinery used. The cable tool rotary drilling method is the oldest drilling method and is still being used to date. The drilling bit is raised and lowered onto the bottom of the hole by the spudding of the drills. A drilling action is created as the cable propels the bit to turn at approximately ¼ revolutions per drop. Distinct from rotary drilling, the drilling action is stopped intermittently in cable tool drilling so that drilled cuttings can be bailed out from the hole. Drilled wells are sometimes cased with a ready-made pipe. Usually steel in air rotary or cable tool drilling, the pipe is usually steel but mostly plastic/PVC in mud rotary wells. The casing is built by welding (either chemically or thermodynamically) segments of the casing together. Casing during the drilling fosters the drills to drive the casing into the ground as the borehole advances. However, some newer machines actually allow for the casing to be rotated and drilled into the formation similarly as the bit advancing just below. PVC or plastic that is typically welded is then lowered into the drilled well. Other welded PVC/plastic is vertically stacked to the end nested and either glued or splined together with the earlier PVC or plastic. Based on the intended use of the well and local groundwater conditions, the sections of casing are sometimes six meters or longer, and fifteen to thirty centimeters in diameter.

Fig. 3 A drilled well under construction.

d). Bored Wells

Bored wells are excavated with earth augers and are usually cased with the concrete pipe. Older dug wells are gradually being replaced by boring wells.

e). Jetted Wells

Jetted well construction employs water with elevated pressure to dislodge soil and wash it away. In solid or partially consolidated formations, a chisel bit accompanied by the jet is used to cut the formation.

2.3. Supply through Borehole

A borehole is a slim shaft bored within the ground, either vertically or horizontally. The primary function of a borehole is the extraction of water, though; it could serve other purposes (mineral exploration, site evaluation, irrigation farming, and stratigraphic research). A water borehole isn't simply a hole within the ground because it has got to be properly designed, professionally made, and thoroughly perforated[15]. Boreholes for extracting water consist primarily of a vertically pierced hole, a robust lining to stop the collapse of the walls, screening to permit clean water to enter the borehole, surface protection, and a way of extracting water from it. Drilling by machine is costly, and its design and construction require input from professionals that are skillful and highly experienced. This method of extracting water incorporates a range of important advantages.

Advantages of the drilled borehole

Drilled boreholes that are adequately constructed and maintained;

- are less susceptible to drought or drops in water level when bored into deep water-bearing formations
- can be designed to draw from more than one aquifer (when individual aquifers are vertically separated and not hydraulicly connected)
- are less susceptible to collapse
- are less exposed to contamination
- are competent to produce large yields, if properly sited, to accommodate the use of mechanically or electrically powered pumps.
- are opened to quantitative monitoring and testing during which aquifer parameters (transmissivity, yield and water supply efficiency) are accurately estimated.

Disadvantages of the drilled borehole

- High initial material prices and input of specialized experts with sufficient experience to effectively carry out the construction operations and subsequent maintenance that may be needed for the effective running of the borehole.
- Open to irrevocable natural deterioration if insufficiently monitored and maintained
- Vulnerable to sabotage, maybe irreparably destroyed with little effort if inadequately protected
- Energy source is required if water extraction pumps are used (unlike gravity feed systems)
- There is no direct access for maintenance and repairs, of constructed parts of the drilled holes that are underground

Methods of drilling borehole

(a) Hand-auger drilling

Auger drills, are operated by hand, digs the soil with blades and pass the cut material up through screw or into a ‘bucket’ (bucket auger). Excavated materials are removed continuously while the augering continues till the specified depth is reached. Auger drilling by hand is slow and restricted to a depth of about ten meters (maximum twenty meters) in loose deposits (not coarser than sand), Auger drilling is a low priced and uncomplicated drilling method. An example of Hand Auger is given in Fig. 4.

(b) Jetting

In Jet drilling, water is pumped down a sequence of rods which emerges as a jet that cuts into the formation. Drilling is aided by rotating the jet or by moving it up and down within the hole. The circulating water washes the cuttings coming out of the borehole. Jetting drilling is functional only in unconsolidated formations and can drill only to a relatively shallow depth. Drilling is closed if a boulder is intersected.

(c) Sludging

This is a reverse jetting method that involves lowering a pipe (bamboo can be used) into the hole and moving up employing a lever arm. Pumping action is initiated by a one-way valve often by placing a hand at the top of the pipe. Water is made to circulate to and fro (with debris) up the drill pipe. The drilling operation is enforced by the simple metal teeth at the cutting end of the pipe [16]. A small reservoir is provided at the top of the hole for the recirculation of water. Sludging has similar limitations to Jetting and Hand auger drillings, but it has been used successfully in Bangladesh.

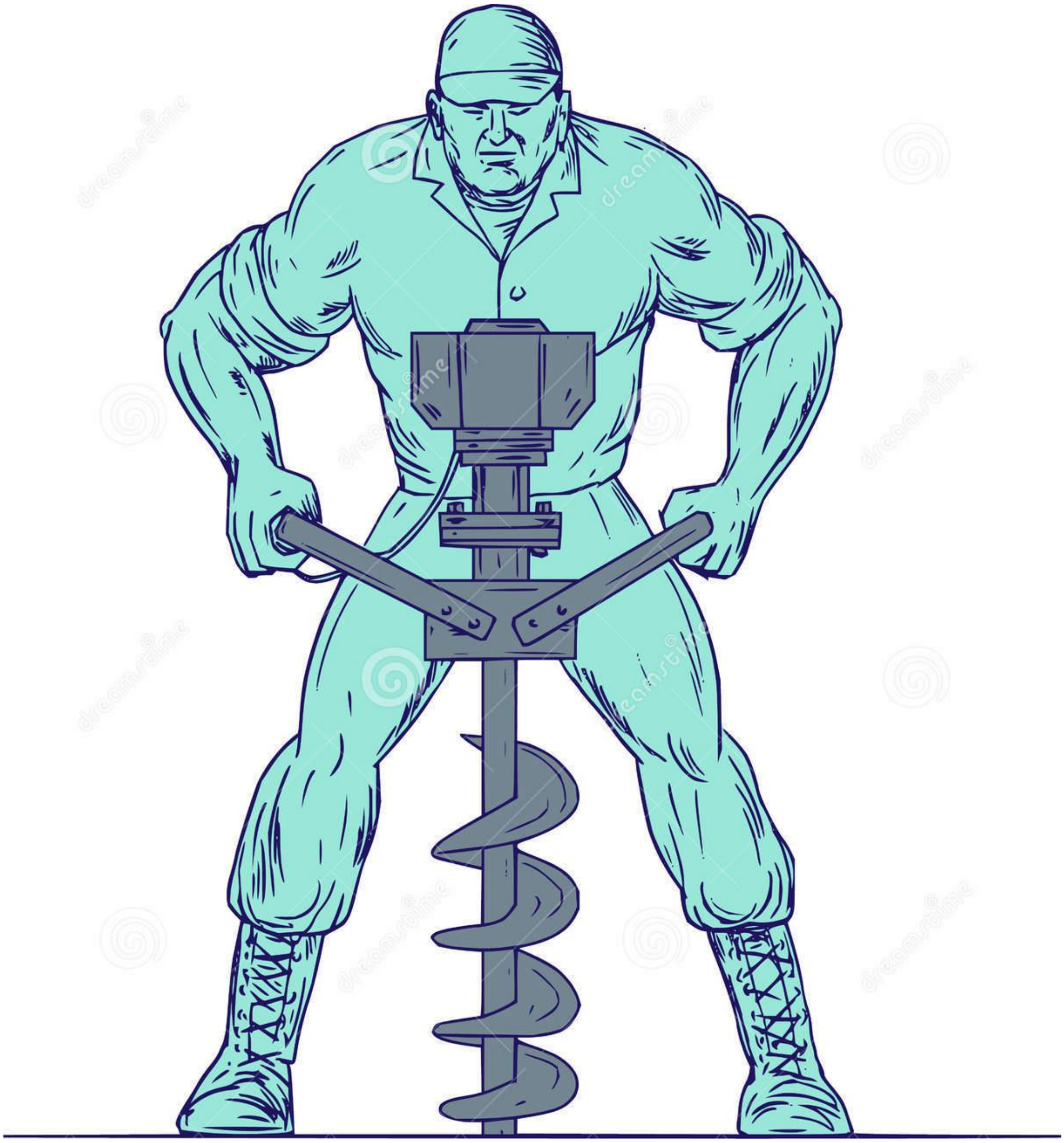

Fig. 4. An Example of Hand Auger being operated by a construction worker

(d) Percussion drilling

Percussion drilling is carried out by merely dropping a heavy cutting tool of weight ≥50 kilograms, continually in the hole. This original method of drilling for water originated in China over 3000 years ago. The heavy cutting tools are normally hung by a rope or cable. Considerable depths can be attained, both in hard and formations employing this drilling method, depending on the weight of the drill string, which is limited for manual operation. Shallow boreholes, operated by hand pumps are commonly drilled in Pakistan using percussion drilling systems. The drilling systems comprise of a strong steel tripod, cable and power winch, percussion tools, and a bailer [17]. These systems are gravely hampered when in hard terrains, and can inadvertently change direction along weaker zones, causing boreholes to become warped or tools to squash. Unconsolidated materials become difficult to drill employing a cable tool when boulders are present in the formation. Apart from the presence of boulders, muggy shales and clays are also difficult to penetrate with cable tool rigs. In addition, loose sand tends to cave into the hole almost contemporaneously as it can be bailed. These manual shallow drilling techniques can serve as low-cost alternatives in groundwater investigations for dug well sites, especially where geophysical surveys may not be available or ineffective because of difficult terrains. When drilling operation is for prospecting only, small holes may be rapidly drilled in such situations.

(e). Rotary drilling

Rotary drilling is applicable to most borehole applications in the field and capable of accessing much deeper formations than most drilling techniques. During the drilling operation, circulating fluids (in form of compressed air and pumped water with additives) are used to cool and lubricate the cutting tools and to take away debris from the hole. An example of a Rotary Drilling Rig is provided in Fig. 5.

Impact of Urbanization on Groundwater Distribution

One of the indices of urbanization is the growing population. Humans’ agglomeration in a specific place on the globe has resulted in the manifestation of increased anthropogenic activities. Increased anthropogenic activities have greatly impacted groundwater distribution negatively in many instances.

Subsidence and saline intrusion

Settlements by humans are often dictated by economic activities. In view of the high economic activities close to the coast, there have been urban settlements close to sea coasts. Saltwater intrusion and land subsidence constitute the most prevalent groundwater problems arising from overexploitation due to an upsurge in population in such areas. Mexico City, as an example, suffered the detrimental effects of intensive groundwater use in the form of land subsidence for nearly 70 years. Heavy groundwater exploitation from deep aquifers began in the late 1920s and this led to subsidence in the central parts of the city in 1959 at a rate of 40 cm/yr [18, 19]). The event resulted in the drop of land surface by over 9m in some locations [20]. The problems were reduced drastically especially in the capital city of Mexico by redistribution of wells, though much of the initial damage remains. Some of the problems include interruption of underground water mains and sewer pipes leading to severe losses, structural damage to roads and buildings, and foremost alterations to surface drainage conditions. The report has it that those other large cities with intensive groundwater demand also experienced land subsidence. Invasion of land by sea is a common hazard in the coastal environment. Cities like Houston, Jakarta, Shanghai, Venice, Calcutta, Taipei, Tokyo, and Bangkok, are all located in coastal areas and parts of the cities can subside and open to invasion by the sea. In 1910, Tokyo, the most heavily populated coastal city in the world experienced ground subsidence due because of the intensive use of groundwater. During World War II, many industries were damaged and this led to a reduction in the use of groundwater and provided brief relief. However, in the early 1950s, many industries resurfaced, and demand for groundwater increased leading to a resumption of subsidence at an accelerated rate. Subsidence of over 4 m was recorded in some parts of the city with the land getting to about 1 m below mean sea level. The subsidence effect was felt more in areas open to tsunamis (areas with high storm surges and waves typhoons). The problem of subsidence was not left unabated. Counter measures employed in the 1960s to combat the problem include elevating the river banks and the erection of a sea barrier, in addition to a planned reduction in the withdrawal of groundwater. Up to date, subsidence is confined mainly to the Kanto Plain, which underlies the northern suburbs of the city as other problem areas have been addressed appropriately.

Fig. 5. Rotary Drilling Machine mounted on a Truck

As a result of the various steps taken to mitigate the subsidence problem, there was the long-term recovery of freshwater reserves, the cost of pumping groundwater was reduced and the potential subsidence cases were lessened. Subsidence is not the only problem associated with the massive withdrawal of groundwater in coastal cities. Groundwater quality can be impaired due to saltwater intrusion. Saltwater intrusion is the flow of seawater into freshwater bodies like rivers or aquifers due to natural processes or human activities. Salinization of groundwater within the very deep aquifer could arise from geologic activities and rock-water interactions over a long period (geologic period). Mixing of saline water with fresh water in the shallow aquifer can occur when water is drawn from the wells tapping the deep aquifer. The saltwater intrusion is as a natural phenomenon arising from density differences between the seawater and the freshwater with the denser saltwater forming a wedge that can extend for many kilometers inland [21, 22]. When freshwater is being withdrawn rapidly, it is displaced by the denser seawater. The salty water body is drawn into the aquifer as the fresh groundwater is withdrawn. Noteworthy usefulness of saltwater intrusion is that if it is properly managed, it can reduce the rate at which groundwater levels are lowered during periods of over-development.

Improper management of saltwater intrusion can result into the saline water entering into the pumping wells, causing degradation of the water quality. Much longer time of reduced pumping is required for an aquifer to recover, once degradation has occurred. Saltwater intrusion into coastal aquifers is a common problem for many coastal cities like Manila and Jakarta. It is important to note that any coastal cities (Dakar, Senegal and Lagos) with excessive withdrawal of groundwater can be affected by saline water intrusion [23].

Similar subsidence problems are prevalent in inland cities due to excessive pumping. The excessive pumping can draw deep bodies of connate or fossil saline water into the pumping wells. In Bangkok, the capital of Thailand, the intrusion of saline groundwater has occurred in response to an increase in groundwater abstraction from just over 8,000 m^3/d in 1954 to 1.4 Mm^3/d in 1990 [24]. The potentiometric surface was locally reduced by as much as 60m. In Manila, a similar increase in groundwater use has lowered the potentiometric surface locally to between 70 and 80m below sea level. In some instances, the decline rate happened at a rate of 5–12 m/yr. It is not strange that saline water from Manila Bay extends inland as much as 5 km, and water samples that were drawn from wells in the coastal areas exhibit chloride concentrations in excess of 200 mg/L. High concentrations, up to 17,000 mg/L chlorides have been noticed. Similarly, Jakarta pumps only 0.65 Mm3/d of groundwater with groundwater levels declining from 1–3 m/yr to reach a more moderate potentiometric surface of 20 to 40 m below sea level. Nevertheless, its medium-to-long-term supply problems are equally severe. A recent Asian Development Bank technical cooperation program on water resources management in megacities presented case histories for these cities. As reported by [25], efforts in these cities to reduce groundwater abstraction in favor of imported surface water have largely failed. Monitoring municipal wells is not difficult, but controlling a very large and escalating number of shallow, privately operated groundwater sources that are erratically located, mostly unregulated, and unmonitored is impossible.

Nigeria has a long coastline covering about 1000km with the Atlantic Ocean bordering eight states (Lagos, Ogun, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom, and the Cross River States). Settlement is usually along the coast attributable to business opportunities. Saltwater intrusion into freshwater has drastically affected the potability of groundwater in some of the communities along the coasts [26]. The study by [27] indicated that the Coastal Plain Sand aquifer unit in Lagos is under severe threat of continued saline water intrusion on its southern flank. Management of coastal aquifers in Nigeria is problematic due to several factors. Amongst these factors are; a lack of sufficient knowledge of the nature of the saltwater intrusion and unrestrained development of both unconfined and confined aquifers in industrial centers like Lagos, Port Harcourt, Warri, and Bonny. In addition, included in the factors are improper sealing of abandoned boreholes and reduced access of rural indigenous people in coastal areas (especially in the oil-producing areas) to potable water supply due to perceived lack of freshwater resources in these areas [26]. Hydrochemical analysis of groundwater quality along the coastal aquifers in part of Ogun Waterside, Ogun State, southwestern Nigeria [28] indicated a Na-Cl dominated water exhibiting slightly acidic with fresh to the saline character. More detailed hydrogeophysical studies are required in the coastal areas of Nigeria to determine the hydrogeology and the nature as well as extent of saltwater intrusion to ameliorate and prevent further encroachment of saltwater.

Impact on Groundwater Quantity

There is considerable evidence that urbanization significantly alters recharge to the groundwater system by modifying prevailing inflow mechanisms and introducing additional sources of aquifer replenishment. Naturally, undisturbed systems groundwater recharge normally results from the direct and indirect infiltration of incident precipitation. The recharge is controlled by the intensity and volume of precipitation, the soil condition, vegetation type, and surface slope [29]. Urbanization can affect parameters either in a subtle way by modulating the microclimate, or more profoundly by sealing large areas of the ground surface with impermeable materials and significantly increasing surface water runoff. In a typical urban environment where about 50% of the land area becomes impermeable, direct recharge will be reduced by a comparable amount [29]. A reduction in direct recharge is usually offset by an increase in indirect recharge. Indirect recharge is common in urban depressions, channels, and valleys that receive additional surface water runoff and in areas immediately adjacent to large impermeable zones such as parking lots [30]. In some instances, indirect recharge can be enhanced artificially by employing infiltration basins and columns [31] which permits the drainage of excess water into the sub-surface with minimal evaporation. Though the spatial and temporal distribution of the recharge is significantly altered, thorough investigations of some areas along Long Island, New York indicate that losses from urbanization are completely offset by stormwater recharge basins [32, 33]. Report has it that urbanization caused a 12% increase in total recharge and a 1.5 m rise in the water table in areas where urban storm water was recharged via large infiltration basins, and a 10% decrease and 0.9 m fall in areas where storm water was released to the sea. Examples of these findings are documented in South Africa [34] Australia [35] and Bermuda [36]. [37] revealed that artificial recharge under specified conditions can be ameliorated using injection wells to introduce stormwater into underlying aquifers. Recently, the general belief that in the absence of artificial recharge management, there is an automatic reduction in the amount of water replenishing an aquifer due to impermeable surfaces in urban areas has been proved to be otherwise. Obviously, direct recharge is reduced and the deficit can rarely be offset by increased indirect recharge. However, it has been observed that any loss of recharge by this method does not essentially lead to a net loss in aquifer replenishment. The urbanization mechanism radically changes the whole water balance of an area [38, 39, 40, 41] and alien sources of aquifer recharge completely new to the region are introduced to compensate for the loss. New possible recharge sources include septic systems, leaking sewers, leaking water mains, and excessive irrigation of gardens and parklands. Quantification of recharge contribution from these sources may be difficult, as indicated by [42, 39]. Only 10% of the supply from well-maintained systems may be lost. On the other hand, higher loss ≥70% at the other extreme has been reported [43]. The report of [44] indicates an average leakage rate of 17% for 18 cities in Latin America. The leakage rate doubles the natural rate of aquifer replenishment [40]. Cases of average leakage rates approaching 25% have been observed by [45]. In cities where groundwater is the main source of water supply, high rates of recharge arising from supply network losses are of no problem. The high rates of recharge are simply a reflection of an inefficiency, which, if rectified, would not produce any net difference in the groundwater budget, but would save substantial pumping expenses. However, in cities where the main water supply is through importation, water mains leakage tends to be more serious. For example, network losses of 15%–25% would provide a substantial contribution to the underlying aquifer in cities importing water with a correspondent depth of between 300 and 5,000 mm/yr. In temperate regions, such leakage might simply offset the loss of direct recharge that results from the broad imperious cover; in arid and semi-arid areas, leakage may be the main groundwater recharge source. In some areas in the Middle East, recharge of aquifers from imported water exceeds natural recharge with their replenishment capacity exceeded [46]. The issue of imported water exceeding natural recharge is more pronounced in cities like Ryadh, Saudi Arabia, Dohar, and Qatar due to over-irrigation of amenity land (parks, gardens, and landscaped areas), particularly if water is applied through flooding from irrigation channels or hosepipes [47, 48, 49]. In some districts (Lima and Peru) with elevated earnings, irrigation resulted in generating 250 mm/yr of additional recharge which is a ten-fold increase over natural recharge rates [50]. In urban centers that utilize septic tanks, it is generally accepted that generated wastes ultimately recharges the aquifer. This case is observed in Bermuda where septic discharge is supposed to account for over 35% of the total annual aquifer recharge. In Buenos Aires, Argentina, over 50% of the urban area is served by septic tanks, the gross recharge from which is estimated to be 3,000 mm/yr, a six-fold increase over recharge in uninhabited areas [40,42] have suggested that for cities where sewage is not exported, as much as 90% of the total water imports may eventually recharge the local groundwater system. In many cities, water that recharges the underlying aquifers is grossly reduced due to wastewater that is being exported using canals and sewage pipes. In Mexico City, unlined drainage enhances the discharge of about 90% of untreated sewage into a sewer system. Unfortunately, the occurrence of subsidence in central parts of the city has locally resulted in a reversal of flow in the canals, necessitating the mounting of a series of continually operating pumping stations for the maintenance of the outwardly flow of wastewater. A more aggravating problem is leakage through the walls of the canals, in which a significant quantity of contaminated water returns to the aquifer. The dilemma facing the Mexican authorities is that while leakage of wastewater may degrade groundwater quality, local groundwater resources are so seriously over-exploited that groundwater recharge is at a premium. Most modern cities are serviced by underground sewers. In some of these sewers, leakage may arise due to faulty seals along joints, breakage because of subsidence, or weakening as a result of age [51, 52]. In some cases leakage leads to ground collapse [53]. Unfortunately, sewer exfiltration rates are very difficult to estimate with most published work concerned with sewer pipes constructed below the water table which receive infiltration from the groundwater. When sewers are constructed in the unsaturated zone, similar flows might be expected to occur in the reverse direction, though, little is known because most studies of sewer pipe exfiltration focused on water quality rather than quantity. In one study of the Permo-Triassic aquifer underlying Liverpool, UK, a water balance conducted by the [54] suggested that leakage from a very old combined storm-sewer system was comparable in volume to water mains leakage. [55] suggests, however, that since sewer pipes are normally unpressurized, leakage from sewer pipes should normally be quite small. In Australia, it is estimated that exfiltration from sewers is about 1%, representing 10 Mm^3/yr [56]. In

Germany, sewage exfiltration rates from leaking, and damaged sewers are approximately 15 L/d per person, accounting for 100 Mm^3/yr of aquifer replenishment [57]. In many large cities, leakage from septic systems, sewers and water mains, combined with the over-irrigation of amenity areas, far exceeds any losses in natural recharge caused by the presence of impermeable surfaces. Where the original source of the additional water is groundwater pumped from beneath the city, the effects of leakage can go unrecognized unless groundwater quality is affected. The additional water simply offsets, at least partially, any aquifer overdraft. It is where significant volumes of water are imported from outside the city and losses can translate into a significant rise in the regional water table. In turn, this can cause flooding of streets, cellars, sewers, septic systems, utility ducts, and transport tunnels, reduces the bearing capacity of structures, and impact amenity space by water logging sports fields and killing trees[58]. The problem is exacerbated most especially in low storage, poorly transmissive aquifer systems in which additional water is not readily accommodated. In Baku, Azerbaijan, the water table has risen to within meters of the surface and recently initiated a major urban landslide. Rise in water table constitute a particular problem in growing cities where large quantities of groundwater are pumped but subsequently abandoned the groundwater usage in favor of imported surface water supplies. In this type of scenario, there are rising water levels as a result of leakage from services combined with the natural long-term recovery of the water levels. These types of scenarios occurred in the UK, where the long-term effects of importing water and rejecting previously utilized groundwater reserves have been particularly reported in cities like Brighton, Birmingham, London, Liverpool, and Nottingham. Local problems arising from this type of attitude include the re-establishment of urban springs, water-logging of low-lying residential areas and upward flushing of salts and contaminants that had previously accumulated in the shallow unsaturated zone [38, 59].

Degradation of Groundwater quality

A key concern associated with urbanization is the introduction of contaminants that can seriously degrade drinking water quality [60, 61]. Contaminants could be from a point source or non-point sources. Potential point source threats include leaks from underground storage tanks containing solvents, brines, gasoline, and heating fuels, municipal waste disposal (landfilling), industrial discharge leaks and spills, stockpiles of raw materials/industrial wastes, and spillages during road and rail transport of chemicals. Distributed and line sources include effluent from latrines and cesspits, leaking sewers and septic tanks, oil and chemical pipelines, lawn, garden, and parkland fertilizers and pesticides, road de-icing chemicals, oil and grease from motorized vehicles, and wet and dry deposition from smokestacks. The effects of non-point sources pollutants are more devastating than point sources. Point sources pollutants often cause localized severe degradation of water quality while non-point sources can affect large areas of an aquifer by simply elevating solute concentrations and bacterial counts to levels that may just slightly surpass drinking water quality standards. Sodium chloride road de-icing chemicals are mostly applied in the snow areas of Northern Europe, North America, and Russia. The applications of the chemicals are mainly recognized as the most serious long-term danger to the quality of urban groundwater [62, 63]. In many other parts of the world, the most serious threat comes from fertilizers and pesticides applied to amenity areas such as parks, lawns, and gardens. For example, [64] showed that over 70% of nitrate detected in groundwaters beneath a fully serviced housing development on Long Island, New York, was attributable to fertilizers. Widespread pesticide contamination of groundwater has been documented in the USA by [65] with pesticide compounds detected in 49% of 208 urban wells. While road de-icing chemicals, fertilizers, and pesticides clearly represent a problem in many parts of the world, urban issues of broader global concern generally fall into three categories: industrial sources, landfills, and wastewater.

Industrial Sources

Urban centers with a long history of industrial activity are often associated with severe cases of groundwater contamination. Industries tend to store, use and generate a broad range of organic and inorganic chemicals and some of this material will inevitably be released to the sub-surface where it can seriously compromise groundwater quality. Very few industrial chemicals have not been encountered on the sub-surface at one time or another. Most industrial toxic materials are point source pollutants, poorly soluble in water, rarely migrate from their source, and as such rarely pose threat to human health. However, industrial toxicants (chlorinated hydrocarbon solvents (CHS), Trichloroethylene (TCE), tetrachloroethylene, 1-1-1 trichloroethane (TCA), carbon tetrachloride (CTC), and chloroform (trichloromethane or TCM) that are readily soluble, mobile and persistent in groundwater, lakes, and streams are dangerous to humans' health on consumption. Most industrial toxicants are released into the aquifer as point source of pollutants due to inappropriate or poor handling, storage, or disposal by industrial users. In Europe, widespread contamination by CHS has been reported in industrialized areas such as Milan, Italy [66] and the UK Midlands [67, 68]. In Birmingham, UK, [69, 70] detected CHS in 78% of 59 supply boreholes tested; 40% of the boreholes contained TCE in excess of the 30 µg/L World Health Organization guideline. CHS contamination is also common in the USA with typical examples described in New Jersey by [71], in Indiana by [72]. Extensive CHS contamination in Australia beneath a residential area in Perth was reported by [73]. Inorganic contamination of groundwater is also common in industrialized areas. Heavy metals, cyanide, and boron are the most frequent offenders. High groundwater concentrations of arsenic, mercury, lead, and cadmium in Madras, India, were reported to be associated with industrial activity [74]. Inadequate facilities for the disposal of industrial wastes were identified as a causal factor. The lack of sewers in industrial areas has similarly been held responsible, at least in part, for heavy metal contamination of groundwaters in South America [40]. In Odessa, Texas, severe contamination of groundwater by hexavalent chromium (locally as high as 72 mg/L), has been caused by the direct release of wastewater into the soil [75], serious hexavalent chromium pollution has also been documented in Buenavista, Mexico [76]. A study by [66] and [77] using Birmingham and Coventry, two of the largest and oldest industrial centers in Europe, report that heavy metal contamination of groundwater is generally rare. Thus in some hydrogeological provinces, the mobility of heavy metals is controlled by the local hydrogeochemical conditions [78]. In areas with elevated concentrations of copper, zinc, chromium, nickel, and cadmium, large metal industry sites appear to be responsible.

Solutions to problems of Groundwater in Urban areas

Several solutions have been proffered to problems of groundwater in urban areas. Some of the solutions are discussed in this study.

Recharge management using artificial recharge

Resource augmentation by human intervention can be of tremendous assistance to most over-developed aquifers. Artificial recharge can be accomplished by diverting stormwater runoff into unsaturated basins through which recharge of the aquifer is directly effected [79, 80, 81]. On the alternative, pumping wells can be employed to induce groundwater recharge from surface water bodies such as rivers and lakes. Historically, design flaws that reduced the efficiency of the artificial recharge technologies are adopted. Report by [82] indicated that clogging and contamination were the main problems associated with artificial recharge. Currently, in urban areas the physical and biochemical processes of artificial recharge are well understood and commonly employed [31], especially in areas where major volumes of additional water are created due to reduced evapotranspiration losses. Artificial recharge not only utilizes this water to augment the groundwater resource but will reduce stormwater runoff and the risks of flooding and erosion that may result. Stormwater is not the only water that can be used for artificial recharge. Current technology permits wastewater to be treated to a level of drinking water quality standards. However, many governments are cautious to allow direct supply of this water for human consumption. Many strategies are available. A tested option in El Paso, Texas is by injecting tertiary-treated sewage directly into the aquifer [83]. Another option is to separate wastes from the large volume of grey water including washing machines, bathtubs, dishwashers, and sinks, from the small volume of black water (human waste), and recharge this water, without or with minimal treatment. Black water that is rich in nitrogen and pathogenic organisms decomposes more readily than grey water. Thus, the quality of grey groundwater is better than black groundwater. Both on-site and offsite recharge systems are practicable employing facilities similar to septic systems. The recharge practices can be costly as either of the recharge systems requires a separate plumbing system to separate the wastes.

Treatment and desalination

Water quality treatment becomes necessary when humans' health is threatened. Chlorination or ultra-violet (u-v) radiation treatments are often applied to water that is unfit for drinking due to bacterial infections so as to make it potable. In a critical situation, u-v units can be installed in houses and apartments where groundwater quality is impaired [84], and the u-v units are employed to produce the quantity of water needed daily for human consumption. Desalination of water is employed in the treatment of water with high levels of total dissolved solids. Though the cost of employing desalination of water may be high due to cost of energy, nevertheless, current technologies for desalination are an economically viable means of providing potable water for the masses, especially if the water is strictly meant for drinking. Desalinization has no direct impact on the intensive use of groundwater in cities since such water is never used to replenish the groundwater resource. Nevertheless, the universal availability of appropriately treated water targeted for potable use would revolutionize the way Groundwater management in terms of protection and utilization in cities may be revolutionized if appropriate water treatment targeting potable water is adopted. Groundwater that was once regarded as unsuitable would suddenly be considered the most cost-effective source of water for nonpotable purposes. Also, planned land use restrictions premeditated to maintain the portability of groundwater would become almost unnecessary.

Water reuse

Separation of grey water from black water at the lot level is necessary to enhance the use former to increase the availability of potable water supplies [85] and treating it centrally before combining it with grey water for secondary treatment. Stormwater can be mixed with the treated water and held for further treatment in a storage pond before being recycled again to households as domesticated water for non-potable uses. This approach is costly because pipes are erected to each household to receive both potable and non-potable services. However, the potential benefits are considerable. Potable water can now be kept for human consumption. The application of water reuse is not limited to households as many types of industry, golf courses, and even cooling systems can also use recycled or grey water with very few or no difficulties.

New groundwater resources and resource mining

The provision of new groundwater resources may not represent a serious option for cities facing severe overdraft problems. However, groundwater resource provision for many cities with severe overdraft problems is a potential solution that is too often disregarded in favor of imported surface water sources as a substitute. The imported surface water alternative may provide reliable short-term benefits but can be injurious in the longer term. [86] recognize that urban groundwater is an underused resource in the UK and it is certainly a viable consideration in cities afflicted by rising water levels. It definitely appears to be an option in Russia, where [87] suggest that many of its cities seriously underutilize groundwater resources. Currently, it is estimated that total groundwater abstraction in the country, including mine drainage, accounts for just 3.2% of the potential safe groundwater yield. Making additional water provision through groundwater supplies (sinking additional wells/boreholes) may also provide a solution for cities where groundwater resources appear to be overdeveloped. It was reported that hydrogeologists working in the Valley of Mexico, argued that there are under-exploited groundwater reserves that could appreciably improve the water supply problems in Mexico City. Whether this proves to be the case or not, further study will tell; however, it must also be recognized that over-development as a policy in itself does not always deserve the criticism it attracts. On the contrary, over-exploitation of groundwater can assist in the economic growth of the city. Excessive exploitation of groundwater necessitates postponement of investment in dams as long-distance transfers and desalination plants are substantially reduced. Overexploitation of groundwater can be especially beneficial if positively planned, realistically evaluated, and if close control over groundwater production is exercised. In view of the fact that the groundwater resources could be exhausted, a clear and feasible plan for an alternative water supply should be envisaged. All over the world, history has it that there is no prosperous nation that has not benefited at one time or other from excessive exploitation of groundwater due to ignorance about the hydrogeology of the area and accompanied long term risks than through a carefully evaluated and planned production strategy.

CONCLUSIONS

This study reveals that high dense population in the urban regions of the world has negative impact on the distribution of groundwater. They result to decrease in available quantity of water since there is large demand for it. Also, large population may result in degradation of water quality through pollution from industrial waste and the people. Most Urban regions of the world are in the coastal area, so saltwater intrusion is another problem affecting the distribution of groundwater in such areas. Furthermore, the study indicated that freshwater (groundwater) is required for the survival and efficient/continuous functioning of ecosystem.

Protecting groundwater resources amidst the prevailing rapid urbanization represent a considerable challenge that is costly to attain. However, it is technologically difficult and economically expensive to treat a contaminated aquifer, groundwater protection measures must be sought beforehand.

REFERENCES

1. Brands, E., Rajagopal, R., Eleswarapu, U. and Li, P. Groundwater. International Encyclopedia of Geography, 2016.

2. USGS. Water Science School. https://wate.usgs.gov/special-topic/water-science- school. Data source: Igor Shiklomanov's chapter. World fresh water resources in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources, 2019.
3. Omole, D.O. Sustainable Groundwater Exploitation in Nigeria. *Journal of Water Resources and Ocean Science*. Vol. 2, No. 2, 2013; pp. 9-14. doi: 10.11648/j.wros.20130202.11
4. Payne, S.M. "Classification of Aquifers," PhD Dissertation, University of Montana, 2010. http://www.kirkenr.com/index_files/ProjectLinks.html
5. Payne, S.M., Magruder, I.A. and Woessner, W.W. Application of a Groundwater Classification System and GIS Mapping System for the Lower Ruby Valley Watershed, Southwest Montana. Journal of Water Resource and Protection/ Vol.5 No.8, 2013,17 pages, DOI:10.4236/jwarp.2013.58079
6. [6] Winter, T.C., Harvey, J.W., Frankie, O.L. and Alley, W.M. "Ground Water and Surface Water: A Single Resource," USGS Circular 1139, 1998, pp. 1-53.
7. Mohammed, A.B. and Sahabo, A.A. Water Supply and Distribution Problems in DevelopingCountries: A Case Study of Jimeta-Yola, Nigeria. International Journal of Scientific Engineering and Applied Science (IJSEAS) - Volume-1, Issue-4, 2015, ISSN: 2395-3470, www.ijseas.com
8. Carrard, N., Foster, T. and Willetts, J. Groundwater as a Source of Drinking Water in Southeast Asia and the Pacific: A Multi-Country Review of Current Reliance and Resource Concerns. *Water* 2019, *11*, 1605. \ https://doi.org/10.3390/w11081605
9. UNEP, Africa Water Atlas. Nairobi, Kenya. United Nations Environment Programme. Division of Early Warning and Assessment (DEWA). EarthPrint.. 2010. 326 p. Accessible on line at http://na.unep.net/atlas/africaWater/book.php.
10. MacDonald, A.M. and Calow, R.C. Developing groundwater for secure water supplies in Africa. Desalination, 248, 2009, 546-556.
11. Oyeleye, O.I. Challenges of Urbanization and Urban Growth in Nigeria. American Journal of Sustainable Cities and Society. Issue 2, Vol. 1, 2013, p 79 – 95. Available online on http://www.rspublication.com/ajscs/ajsas.html ISSN 2319 – 7277
12. Egboka, B.C.E., Mbanugoh, R.E., Nwogute, N.S., Uma, K.O. and Okpoko, E.I. Positive Implications of Hand-Dug Wells in Water Resources Planning and Management in A Developing Economy Such as in Nigeria, Water International, 13:2, 2009, 98-105, DOI: 10.1080/02508068808692008
13. Oluwasanya, G., Smith, J. and Carter, R. Self-supply systems: Urban Hand Dug Wells in Abeokuta, Nigeria. Water Science and Technology Water Supply. 11, 2011, 172 – 178.
14. Ramsey, M.S. Introduction, In Gulf Drilling Guides, Practical Wellbore Hydraulics and Hole Cleaning, Gulf Professional Publishing, 2019, Pages 1-5, ISBN 9780128170885, https://doi.org/10.1016/B978-0-12-817088-5.00001-0.
15. Kane, C., Fussi, F., Diene, M. and Sarr, D. Feasibility Study of Boreholes Hand Drilling in Senegal—Identification of Potentially Favorable Areas. Journal of Water Resource and Protection. 05. 2013, 1219-1226. 10.4236/jwarp.2013.512130.
16. Pedro, Martinez-Santos., Miguel, Martín-Loeches Garrido., Silvia, Díaz-Alcaide. and Kerstin, Danert. 2020. Manual Borehole Drilling as a Cost-Effective Solution for Drinking Water Access in Low-Income Contexts. Water. 12. 1981. 10.3390/w12071981.
17. Han, G., Grant, T. and Bruno, M. Lab investigations of percussion drilling : From single impact to full scale fluid hammer. Proceedings of the 41st U.S. Rock Mechanics Symposium - ARMA's Golden Rocks 2006 - 50 Years of Rock Mechanics.
18. Hunt, S. Quest for Water. International Development Research Centre (IDRC) Reports, October 1990, Ottawa Canada, 8–9.
19. Howard, K.W.F. Over-exploitation of groundwater resources in the developing world. Proceedings of Modern Trends in Hydrogeology. Keynote Address. 1992 International Association of Hydrogeologists Conference. Hamilton, Ontario, Canada, May 10–14 1992, 311–325.

20. Sun, H., Grandstaff, D. and Shagam, R. Land subsidence due to groundwater withdrawal: Potential damage of subsidence and sea level rise in southern New Jersey, USA. Environ. Geol.. 37. 1999, 290-296. 10.1007/s002540050386.
21. Bear, J. Dynamics of fluids in porous media. American Elsevier, New York, USA: 1972. 764 pp.
22. Raudikivi, A.J. and Callender, R.A. Analysis of Groundwater Flow. Edward Arnold (Publishers) Ltd. 1976. 214 pp.
23. Faye, S.C., Faye, S., Wohnlich, S. and Gaye, C. B. An assessment of the risk associated with urban development in the Thiaroye area (Senegal). Environ Geol 45, 2004, 312–322
24. Das Gupta, A. Modelling of groundwater systems: Progress and challenges for Asian developing countries. Proceedings of the Fourth DHI Software Conference, June 6–8 2001. Helsinger, Denmark.
25. Foster, S., Morris, B., Lawrence, A. and Chilton, J. Groundwater impacts and issues in developing cities – An introductory review. In J. Chilton (ed.). *Groundwater in the Urban Environment: Selected City Profiles*. Rotterdam: Balkema,1999, 3–16
26. Oteri, A. U. and Atolagbe, F.P. Saltwater Intrusion into Coastal Aquifers in Nigeria. The Second International Conference on Saltwater Intrusion and Coastal Aquifers — Monitoring, Modeling, and Management. 2003, Mérida, Yucatán, México.
27. Oladapo, M.I., Ilori, O.B. and Adeoye-Oladapo, O.O. Geophysical study of saline water intrusion in Lagos municipality. African Journal of Environmental Science and Technology. Vol. 8(1), 2014, pp. 16 - 30. DOI: 10.5897/AJEST2013. 1554
28. Badmus, G.O., Akinyemi, O.D., Gbadebo, A.M. and Oyedepo, J. Hydrochemical analysis of groundwater quality along the coastal aquifers in part of Ogun Waterside, Ogun State, southwestern Nigeria, Heliyon,Volume 6, .2020. Issue 12, e05661, ISSN 2405-8440,
29. Howard, K.W.F.. Impacts of urban development on groundwater. In E. Eyles (ed.) Environmental geology of urban areas. Special publication of the Geological Association of Canada. Geotext 3, 1997, 93–104.
30. Van de Ven, F.H.M. Water balances of urban areas. *International Association of Hydrological Sciences (IAHS) Publ. No*. 198, 1990, 21–33.
31. Howard, K.W.F., Beatty, B., Thompson, M.J. and Motkaluk, S.D. Advancing technologies in the hydrogeological design of urban subdivisions. In O. Sililo *et al.* (eds.) *Groundwater - Past achievements and future challenges. XXX Congress of the International Association of Hydrogeologists, Cape Town, South Africa, November 2000*: 947–952
32. Seaburn, G.E. and Aronson, D.A. Influence of recharge basins on the hydrology of Nassau and Suffolk Countries, Long Island, New York. USGS Water Supply Paper 2031. 1974.
33. Ku, H.F.H., Hagelin, N.W. and Buxton, H.T. Effects of urban storm-runoff control on groundwater recharge in Nassau County, New York. Ground Water 30, 1992. 507–514.
34. Wright, A. and Parsons, R. Artificial recharge of urban wastewater, the key component in the development of an industrial town on the arid west coast of South Africa. *25th Congress of the International Association of Hydrogeologists / International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia. Adelaide, 21–25 November 1994.* Preprints of Papers NCPN No. 94/14, 39–41.
35. Martin, R.R. and Gerges, N.Z. 1994. Replenishment of an urban dune system. *25th Congress of the International Association of Hydrogeologists. International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia. Adelaide, 21–25 November 1994.* Preprints of Papers NCPN No. 94/14, 21–25.
36. Thomson, J.A.M. and Foster, S.S.D. Effects of urbanization on groundwater in limestone islands: an analysis of the Bermuda case. *J. Inst. Water. Engrs. Scients* 40, 1986, 527–540.
37. Dillon, P.J., Hickinbotham, M.R. and Pavelic, P. Review of international experience in injecting water into aquifers for storage and reuse. *25th Congress of the International Association of Hydrogeologists. International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia. Adelaide, 21–25 November*, 1994.
38. Lerner, D.N. Urban groundwater issues in the UK. 25th Congress of the International Association of Hydrogeologists. International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia. Adelaide, 21–25 November 1994. Preprints of Papers NCPN No. 94/14, 289–293.

39. Lerner, D.N. Too much or too little: recharge in urban areas. In J. Chilton *et al.* (eds.). *Groundwater in the Urban Environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham,* UK, 21–27 September 1997. Rotterdam: Balkema, 41–49.
40. Foster, S.S.D. Impacts of urbanization on groundwater. International Association of Hydrological Sciences (IAHS) Publ. No. 198, 1990, 187–207.
41. Custodio, E. Groundwater quantity and quality changes related to land and water management around urban areas: Blessings and misfortunes. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*.
42. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997*. Rotterdam: Balkema, 11–23.
43. Lerner, D.N. Recharge due to urbanization. In Lerner, D.N., Issar A.S. and Simmers, I. (eds.). *Groundwater recharge*: *A guide book for estimation natural recharge. International Association of Hydrogeologists. International Contributions of Hydrogeology* Vol. 8. 1990a. Hannover: Heise, 201–214.
44. Reed, E.C. Report on water losses. *Aqua* 8, 1980, 178–191.
45. Hueb, J.A. El programa de control de pérdidas como estrategias para el desarrollo de instituciones de agua potable y saneamiento. *OPS-CEPIS Hojas de Divulgación Técnica* 34, 1986. Lima, Perú: 24 pp.
46. Jones, J.A.A. *Global hydrology: processes, resources and environmental management*. Addison Wesley Longman Limited: 1997. 399 pp.
47. Chilton, J. Dry or drowning? Our Planet 9(4). March 1998.
48. Foster, S.S.D., Lawrence, A.R. and Morris, B.L. Groundwater in urban development-Assessing management needs and formulating policy strategies. *World Bank Technical Paper*. World Bank, Washington DC. 1997.
49. Stipho, A.S. Evaluation of potential geotechnical problems associated with rising groundwater level in Riyadh city, Saudi Arabia. In J. Chilton et al. (eds.). Groundwater in the Urban Environment. Volume 1: Problems, processes and management. Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997. Rotterdam: Balkema, 261–267.
50. Walton, N.R.G. Rising groundwater breaks surface: Acase study from the Arabian Gulf. In J. Chilton et al. (eds.). Groundwater in the urban environment. Volume 1: problems, processes and management. Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997. Rotterdam: Balkema, 273–279.
51. Geake, A.K., Foster, S.S.D., Nakamatsu, N. Valensuela, C.F., and Valverde, M.L. Groundwater recharge and pollution mechanisms in urban aquifers of arid regions. *BGS Hydrogeology Research Report* 86: 11, 1986.
52. Seyfried, C.S. Municipal sewage treatment. *Umwelt* 5, 1984. 413–415.
53. Hornef, H. Leaky sewers - problems and responsibilities. *Korrespondenz Abwasser* 32(10): 1985. 816–818.
54. Schenk, D. and Peth, U. Ground collapse in an urban environment: a hydrogeological study of leakage from sewage systems. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 161–165.
55. University of Birmingham *Saline groundwater investigation. Phase 2.* 1984. *North Merseyside.* Final report to the North West Water Authority, UK.
56. Lerner, D.N. Leaking pipes recharge ground water. *Ground Water* 24(5): 1986. 654–662.
57. Eiswirth, M., Heske, C., Hötzl, H., Schneider, T. and Burn, S. Pipe defect characterisation by multi-sensor systems. 2022.
58. Eiswirth, M. Bilanzierung der stofffluse im urban Wasserkreislauf-Wege zur Nachhaltigkeit urbane Wasserresourcen – Postdoctoral lecture qualification, University of Karlsruhe. 2002.
59. Heathcote, J.A. a nd Crompton, D.M. Managing the impact of urban groundwater rise. In J. Chilton et al. (eds.). Groundwater in the urban environment. Volume 1: problems, processes and management. Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997. Rotterdam: Balkema, 597–6

60. Barrett, M. & Howard, A.. Urban Groundwater and Sanitation — Developed and Developing Countries. 2011. 10.1007/978-94-010-0409-1_3.
61. Lerner, D.N.. Groundwater recharge in urban areas. *Atmospheric Environment* 24B(1): 1990b, 29–33.
62. Lerner, D.N. Groundwater recharge in urban areas. *International Association of Hydrological Sciences (IAHS)* Publ. No. 198: 1990c. 59–65.
63. Howard, K.W.F., Taylor, R. and Salvatori, S. The dynamics of groundwater flow in the shallow regolith of Uganda. *25th Congress of the International Association of Hydrogeologists / International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia.* Adelaide, 21–25 November 1994. Preprints of Papers NCPN No. 94/10, 435–440.
64. Nysten, T. and Suokko T. (eds.) *Deicing and dustbinding – risk to aquifers. Proceedings of an International Symposium, Helskinki, Finland, October 14–1 1998. Nordic Hydrological Programme, NHP Report* No. 43, 1998. 269 pp.
65. Flipse, W.J.Jr., Katz, B.G., Lindner, J.B. and Markel, R. Sources of nitrate in ground water in a sewered housing development, central Long Island, New York. Ground Water, 22, 1984, 418–426.
66. Kolpin, D.W., Squillace, P.J., Zogorski, J.S. and Barbash, J.E. Pesticides and volatile organic compounds in shallow urban groundwater of the United States. In J. Chilton et al. (eds.). Groundwater in the urban environment. Volume 1: problems, processes and management. Proc. of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997. Rotterdam: Balkema, 469–475.
67. Cavallaro, A., Corradi, C., De Felice, G. and Grassi, P. Underground water pollution in Milan and the Province by industrial chlorinated organic compounds. In J.F. Solbe (ed.). *Effects of Land Use on Fresh Waters.* Ellis Horwood, Chichester: 1986. 68–84.
68. Burston, M.W., Nazari, M.M., Bishop, P.K. and Lerner, D.N. Pollution of groundwater in the Coventry region (UK) by chlorinated hydrocarbon solvents. *Journal of Hydrology* 149, 1993, 137–161.
69. Nazari, M.M., Burston, M.W., Bishop, P.K. and Lerner, D.N. Urban ground-water pollution - A case study from Coventry, United Kingdom. *Ground Water.* 31: 1993. 417–424.
70. Rivett, M.O., Lerner, D.N., Lloyd, J.W. and Clark, L. Organic contamination of the Birmingham aquifer. *Report PRS 2064-M. Water Research Centre*, Marlow, 1989. UK.
71. Rivett, M.O., Lerner, D.N., Lloyd, J.W. and Clark, L. Organic contamination of the Birmingham aquifer, UK. *Journal of Hydrology* 113: 1990. 307–323.
72. Roux, P.H. and Althoff, W.F. Investigation of organic contamination of ground water in South Brunswick Township, New Jersey. *Ground Water* 18: 1980. 464–471.
73. Kalinski, R.J., Kelly, W.E., Bogardi, I., Ehrman, R.L. and Yamamoto, P.D. Correlation between DRASTIC vulnerabilities and incidents of VOC contamination of municipal wells in Nebraska. *Ground Water* 32: 1994. 31–34.
74. Benker, E., Davis, G.B., Appleyard, S., Barry, D.A. and Power, T.R. Groundwater contamination by trichloroethene (TCE) in a residential area of Perth: distribution, mobility and implications for management. *25th Congress of the International Association of Hydrogeologists. International Hydrology and Water Resources Symposium of the Institution of Engineers, Australia. Adelaide, 21–25 November 1994.* Preprints of Papers NCPN No. 94/14: 261–266.
75. Somasundaram, M.V., Ravindran, G. and Tellam, J. H. Ground-water pollution of the Madras urban aquifer. *Ground Water* 31: 1993. 4–11.
76. Henderson, T. Geochemical reduction of hexavalent chromium in the Trinity Sand Aquifer. *Ground Water* 32: 1994. 477–486.
77. Armienta, M.A., Rodríguez, R., Ceniceros, N., Cruz, O. and Aguayo, A. Identification of the main source of chromium pollution from various potential sources. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment: Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 365–371.
78. Ford, M. and Tellam, J.H. Source, type and extent of inorganic contamination within the Birmingham aquifer system. *UK. Journal Hydrology*, 156: 1994. 101–135.

79. Buss, S.R., Tellam, J.H., Lloyd, J.W. and Harris, R.C. Natural retardation of industrial fluids in the Birmingham urban Triassic Sandstone aquifer. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 97–101.
80. Asano, T. Artificial recharge on groundwater. Butterworth Publishers: 1986. 767 pp.
81. Li, C., Bahr, J. M., Reichard, E. G., Butler, J. J. Jr. and Remson, I. Optimal siting of artificial recharge: An analysis of the objective functions. *Ground Water* 25: 1987. 141–150.
82. Watkins, D.C. International practice for the disposal of urban runoff using infiltration drainage systems. In J. Chilton *et al.* (eds.), *Groundwater in the Urban Environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 205–213.
83. Pitt, R., Clark, S., Parmer, K. and Field, R. *Groundwater contamination from stormwater infiltration*. Ann Arbor Press, Inc. Chelsea, Michigan. 1996.
84. Sharp, J.M.Jr. Groundwater supply issues in urban and urbanizing areas. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 67–74.
85. Limaye, S.D. The role of Indian hydrogeologists in providing drinking water for the urban poor. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 621–624.
86. Booker, N., Priestley, T., Mathes, P., Burn, S., DeSilva, D., Shipton, R. and Mitchell, G. Initial scenario development system design, cost estimation and evaluation, *CSIRO-DBCE working paper T3-05*. 1999. Melbourne, Australia.
87. Barrett, M.H., Hiscock, K.M., Pedley, S.J., Lerner, D.N. and Tellam, J.H. The use of marker species to establish the impact of the city of Nottingham, UK, on the quantity and quality of its underlying groundwater. In J. Chilton *et al.* (eds.). *Groundwater in the urban environment. Volume 1: problems, processes and management*. *Proceedings of the XXVII IAH Congress on Groundwater in the Urban Environment, Nottingham, UK, 21–27 September 1997.* Rotterdam: Balkema, 85–91.
88. Zekster, I. S. and Yazvin, L. S. Groundwater as an alternative source of supply for urban areas in Russia. In K.W.F. Howard & R. Israfilov (eds.). *Current problems of hydrogeology in urban areas, urban agglomerates and industrial centres. NATO Science Series IV, Earth and Environmental Sciences,* Kluwer. 2002. p263 – 271.

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