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Interference between sea water and groundwater

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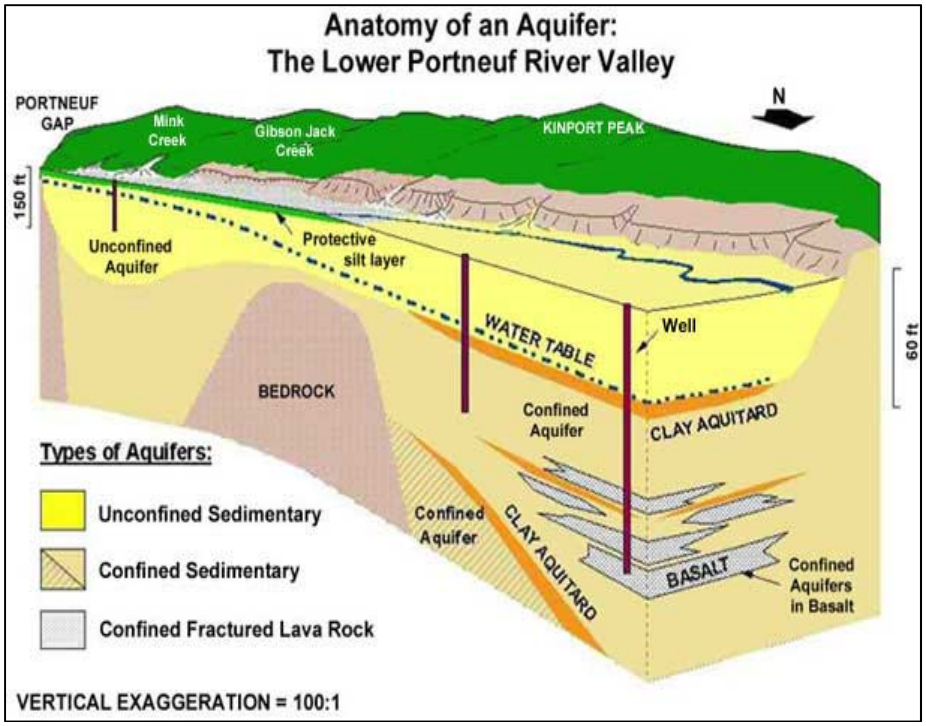
Abstract
Saltwater intrusion occurs naturally in coastal aquifers. It is the saline water movement into freshwater aquifers, leading to degradation of groundwater quality, including impairment of sources of drinking water, including other nasty consequences. The intrusion of saltwater occurs due to the seawater and groundwater hydraulic connection. This review paper explores the research study made, several academic work conducted in the past to understand the concept, cause and effects of freshwater Salinization due to sea water intrusion in groundwater and whether there are any ways to mitigate these effects.

Keywords: Seawater intrusion, groundwater, saline water, aquifers

Introduction

The seawater intrusion is the major reason and problem of fresh water Salinization of aquifers all alongside the coastline. In the extreme inhabited coastal territory, when the people depend mainly on a groundwater supply source, the underground water withdrawal, mostly exceeds the rate of recharge, causing seawater intrusion. Seawater normally intrudes with upward force towards the land around a well, into an aquifer. It can cause with passive moment resulting in the water table lowering near the coastline. The interface transition zone where freshwater usually gets mixed with seawater naturally descends to come over landward forming a wedge within coastline aquifers (Raicy, *et al*., 2012) [28].



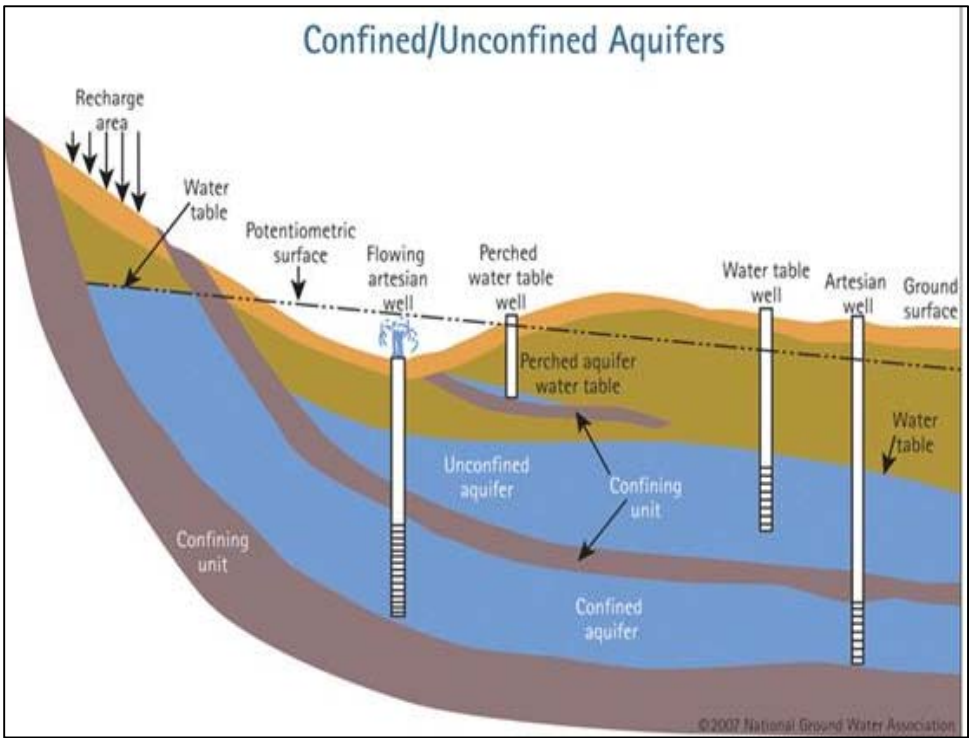


Fig 1: An aquifer look like (Groves, *et al*., 1997) [17].

Aquifers:

An aquifer is formed due to an underground water-bearing layer of rock fractures, permeable rock, and sand, gravel, or silt like unconsolidated materials. Groundwater is extracted from the water wells. The water flows in aquifers and is known as Hydrogeology. The aquifers are a low permeability bed, whereas, there is an impermeable solid region overlying or underlying an aquifer. When the impermeable region is above the aquifer, the developed pressure can cause it to transform into a confined aquifer.

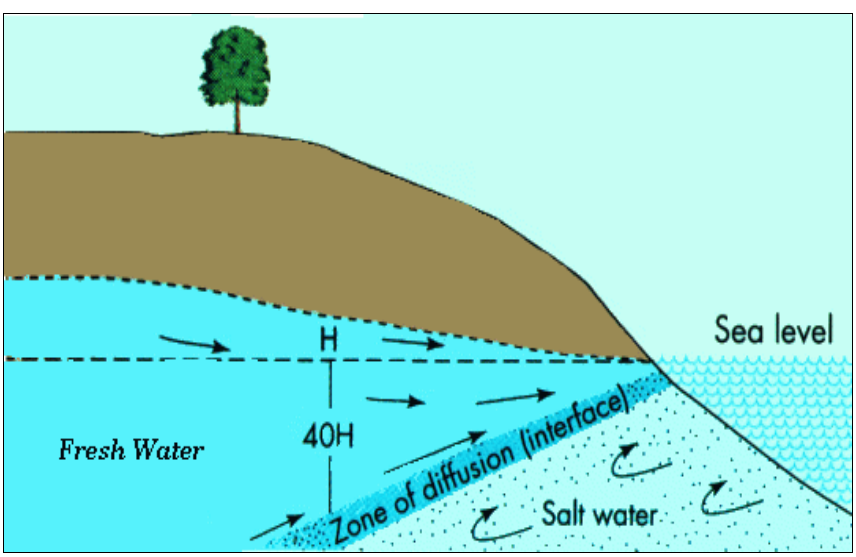
Statement of the Problem

The Intrusion of Seawater is explained as the migration and passage of sea saline water into aquifers, which are hydraulically linked to the seawater. Thus, the intrusion of seawater transforms the fresh water to saline properties of aquifers along the entire coastlines.

Objectives

1. To get a better insight of the procedures affecting the freshwater lens;
2. To identify the impacts of seawater intrusion on ground water;
3. To explore the possibility of the mitigation process of seawater intrusion by managing aquifer recharge.

Intrusion Cause of Seawater



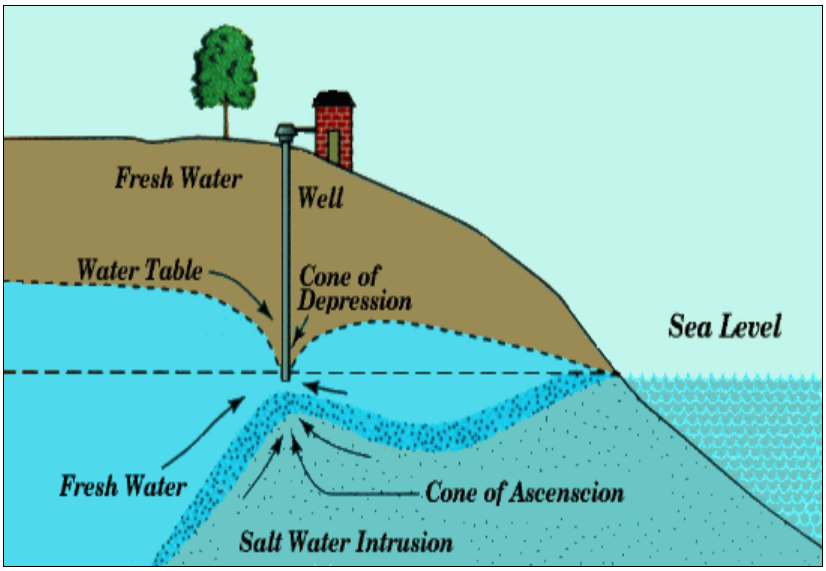


Fig 2: Seawater interference in groundwater (Lenntech, 2020) [22].

The intrusion of sea water is mainly caused due to decrease in the level of groundwater or by increasing the seawater level. When the fresh water is pumped out rapidly, it reduces the fresh water height in the aquifer and transforming into a depression cone. Thereafter, the salt water increases the level by 40 feet for every freshwater depression of 1 foot to form an ascension cone, as shown in the above figures (Lenntech, 2020) [22].

The seawater density is slightly more than fresh water. Therefore, the intrusion of saline water from the sea goes to the aquifer lower surface to reach its bottom level. Whereas, the fresh water floats and remains on the water surface top. There is a boundary formation between the fresh water and salt water and that is not very discrete, but characterized to be the zone of dispersion. The most prominent intrusion cause of seawater is the groundwater reversal gradient in coastal region's aquifers, and this is mainly due to excessive pumping of water from the wells and that disturbs and interrupts the underground hydrodynamic balance.

This is basically caused by the negligent nature of human beings, overpopulation, excessive fresh water needs and resulting in fresh water over pumping of aquifers. Several human activities, particularly in the case of regular groundwater pumping of fresh water from wells in the coastal areas can augment the intrusion of salt water in numerous coastal areas (Johnson, Teddy, 2008). The extraction of sea water process cuts down the fresh groundwater level, decreasing its water pressure, permitting the salt water from the sea to migrate towards the inland further. The other intrusion contribution of saltwater migration is to affect and disturb agricultural, navigation and drainage channels, which provide the added medium for salt water to travel and move inland. The sea water level increase can also cause the saltwater intrusion (Barlow, Paul, 2003) [5]. The intrusion of saltwater can further worsen the conditions resulting in extreme natural calamities like storm, hurricane and water level surges (Lacombe, Pierre & Carleton, 2002) [21]. The entire process fallout in the structural formation of depression cone pattern that outcome into the formation of gradient to move the groundwater in a reverse direction. The eventual result is the clear entry of seawater migrating towards the created fresh water underground zones (Dillon, *et al*., 2009) [10].

Saltwater intruding groundwater

In reality, the intrusion of saltwater is the saline water movement into the freshwater aquifers, leading to degradation of groundwater quality, affecting the sources of drinking water, and further result in more drastic consequences. Also, this Saltwater intrusion process occurs naturally in the coastal aquifers, mainly due to the hydraulic link between sea water and ground water. The saline water contains high levels of mineral contents than fresh water. It has at higher water pressure and is denser, due to which, the salt water is pushed inland below the level of fresh water (Johnson, Teddy, 2008).

Cause of sea water intrusion Problems

This is mainly due to increase in population where the demand for the freshwater exceeds the availability, where over pumping of ground water wells interrupts the hydrodynamic balance. In very populated coastal areas, people are highly dependent on ground water sources. In such cases, the speed of ground water withdrawal normally increases, and it exceeds the further rate of ground water recharge. This mainly causes the intrusion of seawater at the depression level. Seawater normally intrudes upwards, in an ascending manner and towards the land into the aquifer surrounding the well (Environmental Protection Agency, 2019) [12].

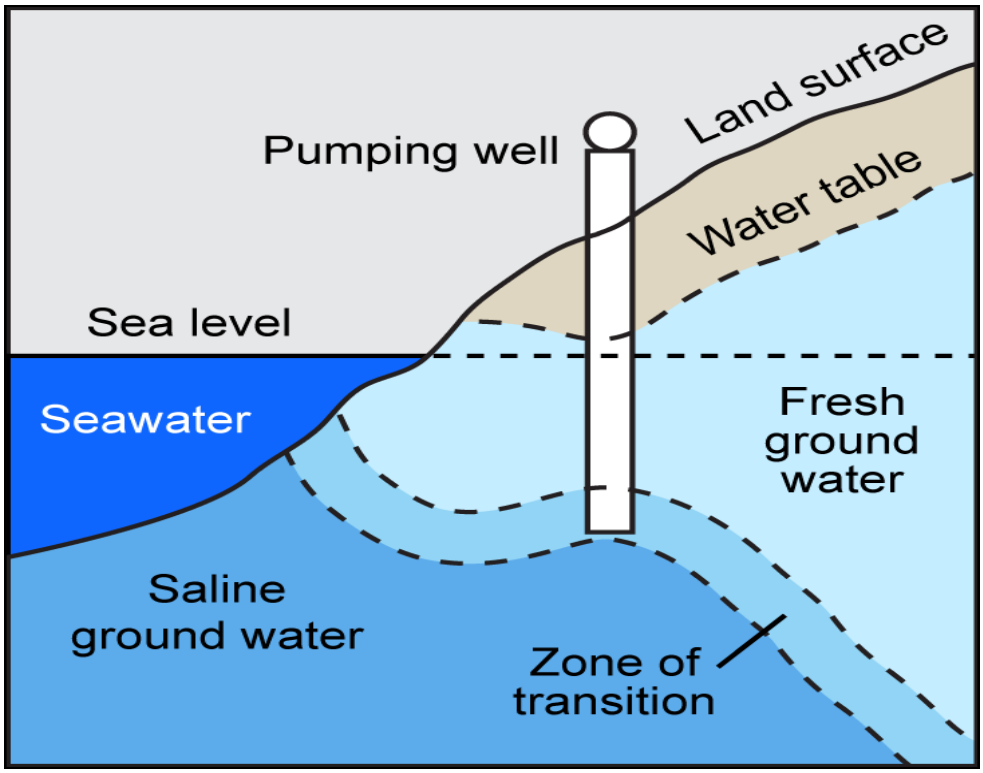


Fig 3: Cause of sea water intrusion Problems (Environmental Protection Agency, 2019) [12].

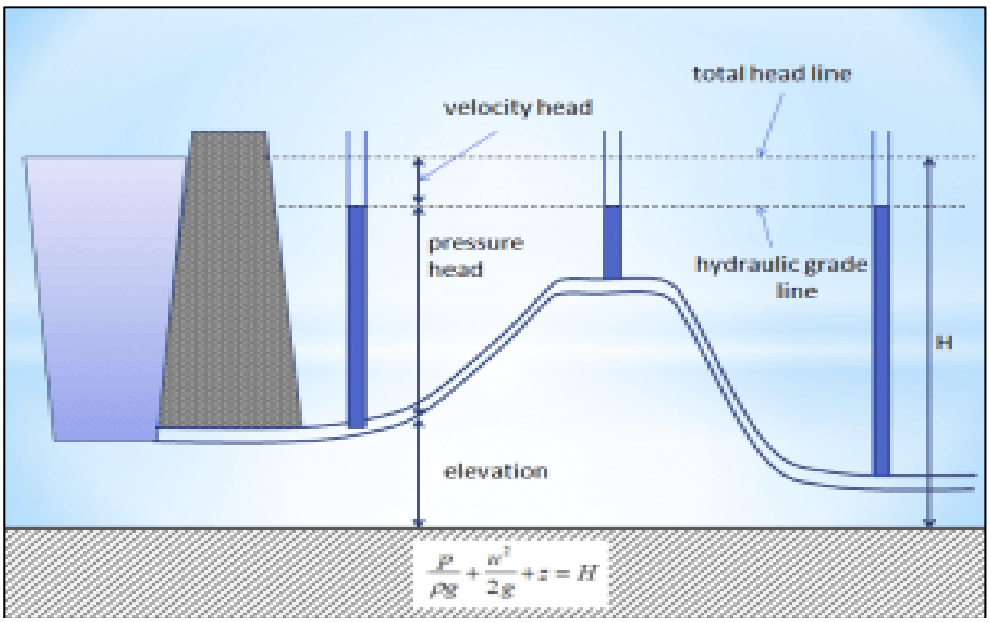


Fig 4: Hydraulic Head (Todreas Neil & Kazimi Mujid, 2012) [34].

Even though it takes place 'passively,' generally resulting in water table lowering near the coastline. This zone of transition, which is the interface of freshwater meeting the seawater with natural mix, is later discharged into the sea, naturally descending landward as the wedge inside aquifers in the coastline length (Muralidharan, Andrade, & Rangarajan, 2007) [23].

The intrusion of seawater further results in the destruction of all the natural surroundings and barriers, which bifurcate saline waters and freshwater. The low permeable dredging of materials near the coastal area can lead to seawater entry inland and also percolating sea water in the groundwater. The intrusion of seawater is the cause due to waste saline water, subsurface disposal into landfills, disposal wells, or other waste collection repositories. In certain regions, the structural dependability of the dispersion zone is not enough due to biological fracturing, hence permitting perpendicular upright intrusion. The intrusion of seawater also due to the groundwater degradation by constant use in the absence of enough outflow, upgrading of brine migration, degradation of

brines or waters from the improvement and groundwater basin formations, through the downward industrial waste, sewage seepage or mineralization of surfacewater from lakes, water streams, lagoons to the strata of ground water table, degradation through saline water migration from bearing formation of one water to another, through the natural impermeable layer breaks through inappropriately constructed well (Lacombe, Pierre & Carleton, 2002) [21].

Hydraulic Head

The Piezometric or Hydraulic head is a specific liquid pressure measure above the vertical datum. Normally, it is measured in terms of elevation liquid surface, expressed in length units, at the Piezometer entrance or its bottom end. In the case of an aquifer, it is measured from the water depth in a specialized Piezometric water well, providing the Piezometer's information of screen depth and elevation. Similarly, Hydraulic head is measured in a water column using a Piezometer standpipe, by measuring the water surface height in the tube with respect to the common datum. The hydraulic head measure is used to find the hydraulic gradient between various points.

Hydrology

The fresh groundwater flow from inland areas meet at the coastal margin, while the saline water from the ocean meets the groundwater. The fresh groundwater flowing from inland regions moves towards the coastal areas where groundwater levels and elevations are lower (Barlow, 2003) [5]. When the high contents of dissolved minerals and salts remain in the salt water, it becomes more dense than fresh water, and that causes more hydraulic head than the freshwater. In fact, hydraulic head is the liquid pressure applied by the water column, while the water column having more hydraulic head will migrate into the water column having less hydraulic head, in case these columns are linked (Johnson, Teddy, 2007) [20].

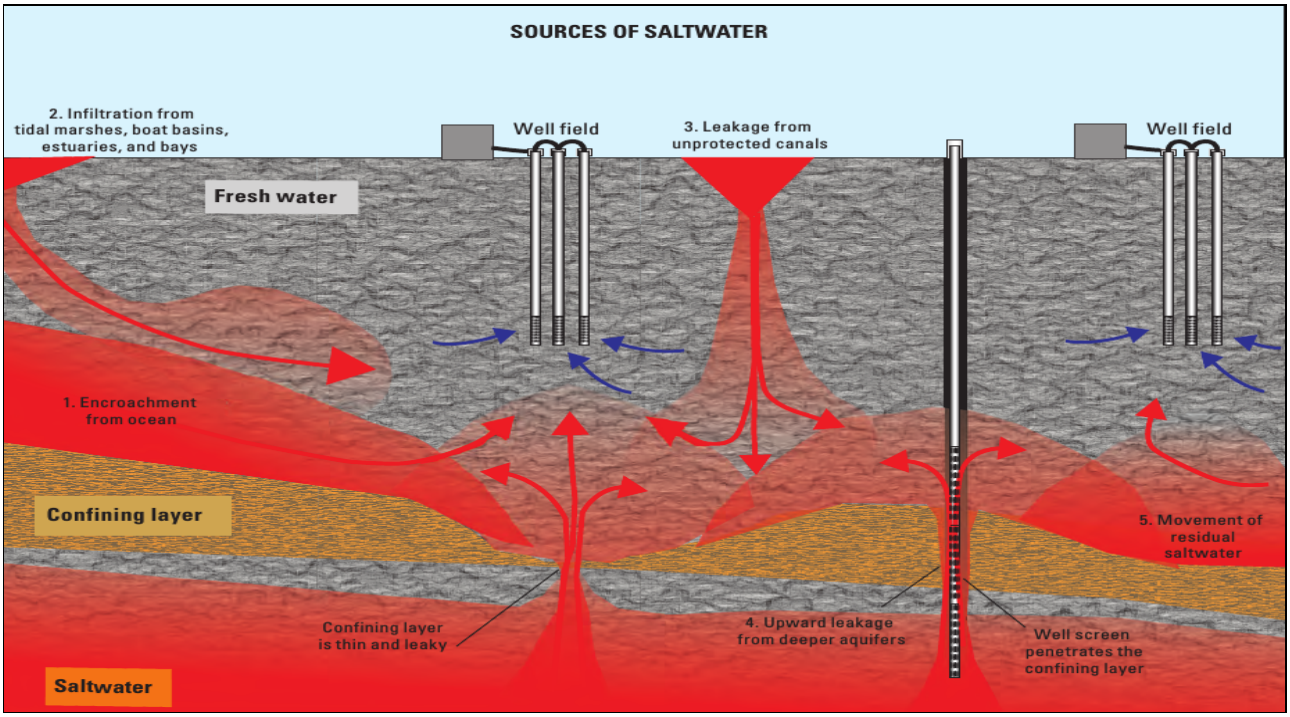


Fig 5: The fresh groundwater flow from inland areas meet at the coastal margin, while the saline water from the ocean meets the groundwater.

The fresh groundwater flowing from inland regions towards the coastal areas where groundwater levels and elevations are lower (Barlow, 2003) [5].

The high pressure and density saltwater cause it to reposition into the nearby coastal aquifers in the form of wedge shape that exist under the fresh water (Polemio, Maurizio (2016) [27]. The fresh water and salt water meet in such transition zone or the interference zone where both types of water mixing takes place by diffusion and dispersion process. Normally, the salt water wedge inland extent is restricted by the level of fresh groundwater, or due to the freshwater column height., and that increases when the land elevation becomes higher (Sivakumar & Elango, 2010) [32].

Mitigation Methodology of Sea Water Intrusion

The managed and controlled aquifer recharge happens to be the best application method for mitigating the intrusion of seawater. The intrusion of sea water has been identified and located in several coastal aquifers by various Geo-chemical, Geo-electrical, and groundwater methods of modelling studies. For the experimental studies, one pilot pond was created to study the percolation pond effect in aquifer recharge. The groundwater potential improvement by this experimental dam showed that the test dam generated remarkable effects by improving the groundwater quality (Raicy, *et al*., 2012) [28].

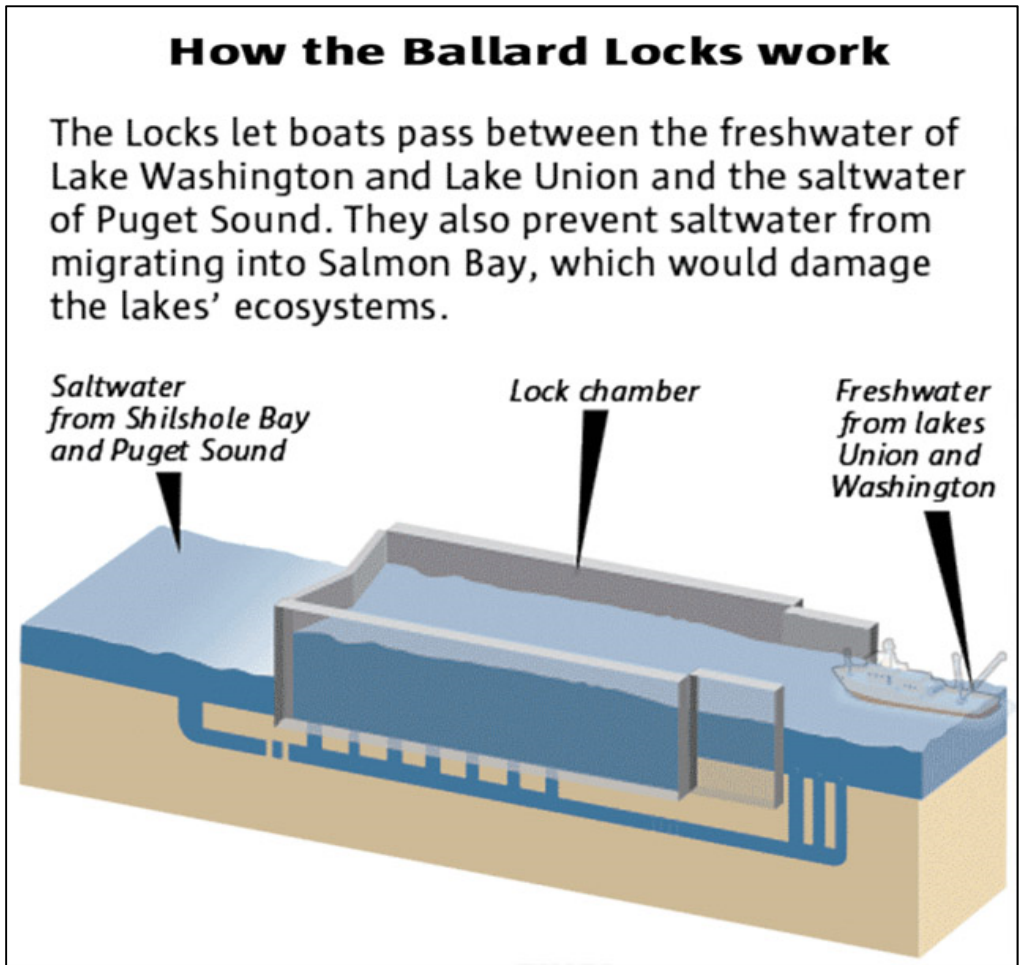


Fig 6: Salt water becomes a major concern when a lock bifurcates saltwater and freshwater, that was observed in Washington Ballard Locks.

A collective basins were constructed from where the salt water was pumped and sent back to the sea water. Part of the obtrusive salt water was further pumped to the fish ladder to make it more attractive to migrating fish (Daniel Beekman, 2018) [9].

Groundwater height measurement

When the groundwater level goes below the sea level, the intrusion of seawater certainly occurs. Therefore, the groundwater head measurement in the coast line vicinity will indicate whether the seawater intrusion in the region has affected.

Geo-electrical study

Geo-electrical dimensions are better investigation methods to understand the seawater intrusion extent and to evaluate the saline contents in ground water. A Schlumberger configuration of vertical electrodes to measure the potential and current are used along the coastal region that clearly show the fresh water ridge in the area (Gnanasundar and Elango, 1999; Senthilkumar *et al*., 2001) [15, 30]. The low resistivity sensor of the eastern margin saline ground water is because of seawater intrusion, while in the western margin it is due to influence of contaminated water carried on the canal (Sathish & Elango, 2011) [29].

The fresh water encountering in aquifers probably of the coastal region has reduced considerably because of the saline water influx from the sea water towards land. The intrusion of saline water is an observable fact wherein in inflow of salt water gets displaced and mixed with fresh groundwater in coastal aquifers because of the density variation of waters of diverse salinities. In reality, the pattern of groundwater flow prevents saline sea water from encroachment in the coastal aquifers, creating the saltwater and freshwater interface, maintained below the land surface near the coastal region, (Oloruntola, Folorunso, & Bayewu, 2019) [4], known as transition zone or dispersion zone as shown in the below figure.

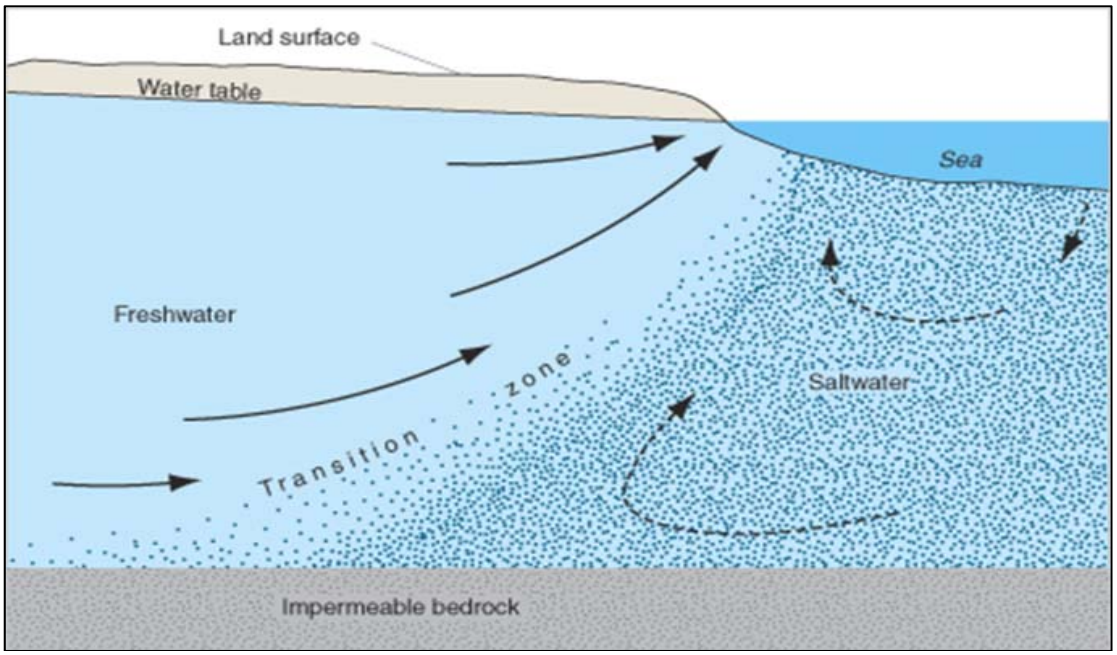


Fig 7: An idealized coastal region of the aquifer, where it shows the ground water pattern of flow and the transition zone of freshwater and saltwater (Oloruntola, Folorunso, & Bayewu, 2019) [4].

Similarly, there are Geochemical studies by locating the dominant anions and cations in the ground water of the coastal aquifer and they are in the sequence of: {Sodium (Na); Calcium (Ca); Manganese (Mg); Potassium (K); and Chlorine (Cl); Hydrogen Bi carbonate (HCO3); Sulphate (SO4); Nitrate (NO3); Iron (F)} respectively.

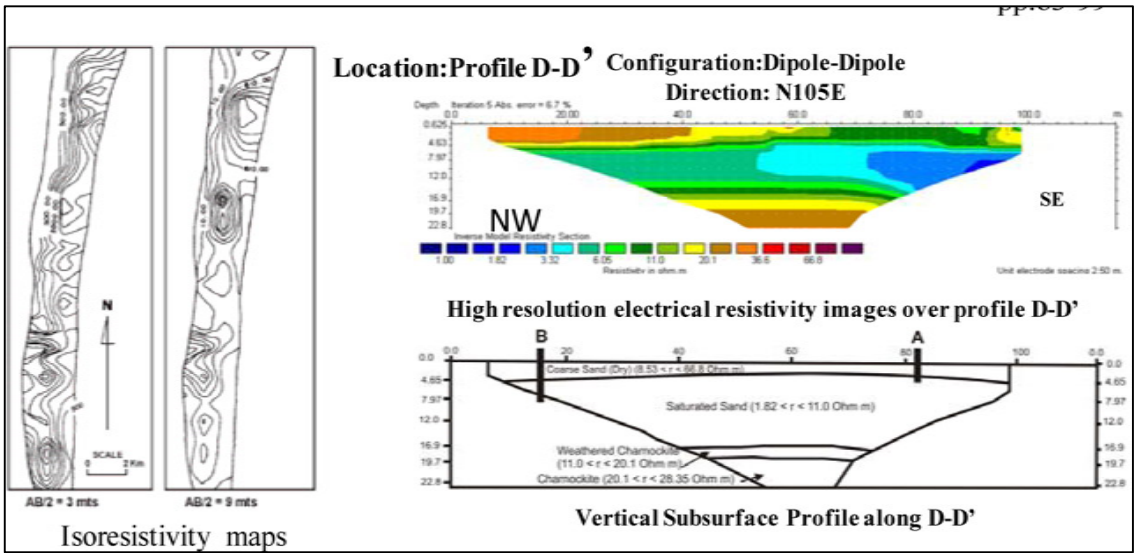


Fig 8: Vertical subsurface of coastal aquifer (Sivakumar, 2008; Sathish & Elango, 2011; Raicy, *et al*., 2012) [31, 29, 28].

Sodium chloride (NaCl) is mixed in water and remains dominant in several segments of the aquifer (Sivakumar, 2008) [31]. The major ion concentration also indicated in certain regions from west to increase in the eastern regions. The data on Hydro-chemicals indicated that the east deep wells are more saline, and the Geo-chemical analysis confirms the existence of saline groundwater is reasonably scattered in the coastal region (Sathish and Elango, 2011) [29].

Studies of Isotope

Isotope study can be applied for several Hydrological and Environmental applications. The 2004 tsunami impact on the resources of groundwater were taken from studies by Sivakumar (2008) [31] to observe the link between deuterium and oxygen-18 of the samples obtained from groundwater samples. It showed that besides six out of many groundwater samples, all other samples were seen near the water meteoric line, showing the meteoric origin. There was oxygen-18 and deuterium connection in the groundwater specified the process of evaporation (Muralidharan, Andrade & Rangarajan, 2007; Raicy, *et al*., 2012) [23, 28].

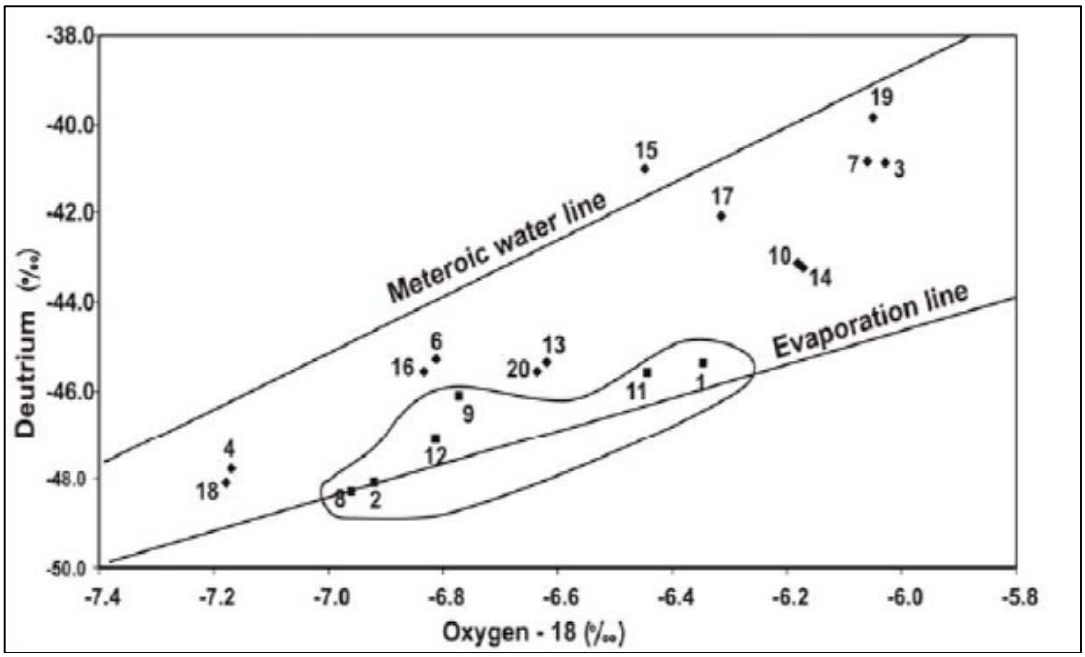


Fig 9: Groundwater Deuterium and Oxygen-18 Correlation of (Sivakumar, 2008) [31]

Groundwater modeling:

Another Groundwater model was performed using FEFLOW and MODFLOW for the designated coastal regions of South India (Gnanasundar & Elango, 2000; Sivakumar *et al*., 2006; Sivakumar & Elango, 2010) [16, 32]. The located aquifer was under high stress because of groundwater pumping to endure the mounting water needs of people in the city. Hence, Groundwater modelling work was performed to obtain the intrusion of seawater with several abstraction stages and methods. This Modelling was further applied to obtain the influence the groundwater water flow system because of constant pumping continued by the desalination works. Having the horizontal well possibility to pump out seawater for to feed the desalination plant was evaluated (Raicy, *et al*., 2012) [28].

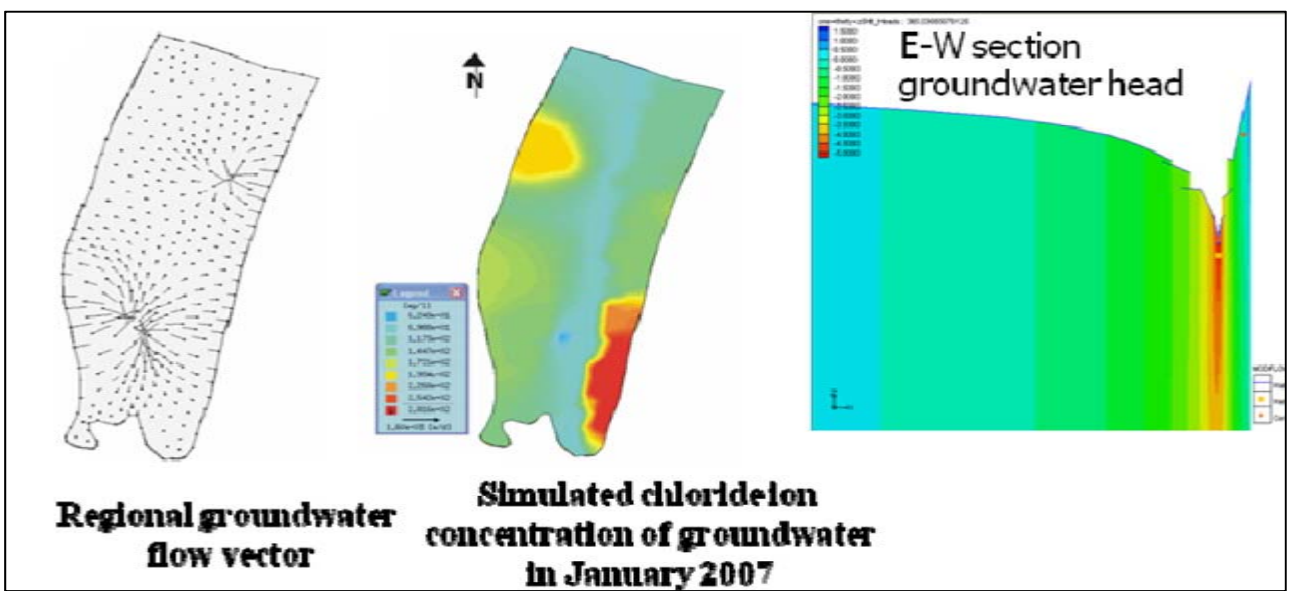


Fig 10: The coastal regions Groundwater modelling (Sivakumar and Elango, 2010) [32]

Literature Review

The problem of seawater intrusion and Identification was known in 1854 in NY, USA (Back and Freeze 1983) [4]. The main cause of problems was based on dominant anthropogenic and geologic factors. Because of ever-increasing population of those inhabited coastal areas there is a mounting saline water rate of intrusion, mainly because of increasing rates of pumping water for daily use. This disrupted the hydraulic pattern of flow. Almost 65% global population is staying within the ocean shoreline vicinity of 400 km, while 50% stay within a 200 km area and they occupy 12% of the entire Earth's surface (Hinrichsen 2007)

[18]. They mostly depend on groundwater of coastal regions as the major freshwater source for industrial, domestic and agricultural reasons.

It is imperative to monitor the possible intrusion risk of saline water into the coastal aquifers. This is because, when the saline water encroaches the coastal aquifer, it becomes very complicated to improve and overcome the water resource management considering long-term strategy. In this connection, earlier, Custodio (1987) [8] had established that below 2.5% intrusion of seawater in the freshwater can reduce the potability of water. The bore well holes have got affected when such things occur, and hence, have to be discarded to look for other water sources, always at very high cost. There are contamination of saline water problems in coastal aquifers mainly due to a violation of Hydro-geological balance that prevails between seawater and freshwater in coastal aquifers (Goldman & Kafri 2004) [13]. The intrusion of saltwater transpires in all coastal aquifers, because they maintain seawater hydraulic continuity. There are several zones of subsurface brackish water developed because of mixing of saline water and fresh water in those zones (Choudhury *et al*., 2000) [7]. The problems are related to groundwater pressure in coastal regions as emphasized by Capizzi *et al*. (2010) [6]. The major risks and problems of seawater intrusion is due to industrial, agricultural, and chemical contamination (Capizzi *et al*., 2010) [6], and when such contamination occurs, restoration of groundwater can be done by groundwater abstraction pace reduction, relocation, increasing natural process of recharge, by artificial recharge, applicable erosion control procedure, along with saline water abstraction.

In many parts of global arena, numerous studies have been performed on the geophysical surveys of the coast region to measure the interaction of freshwater and saline water along with efficient groundwater management (Capizzi *et al*. 2010; Eloisa *et al*. 2012; Idowu *et al*. 2017) [6, 11, 19]. In some places where the coastal area extends east–west direction entirely, some attempts have been processed using Geo-chemical and Geophysical techniques (Adepelumi *et al*., 2009) [2] to solve the intrusion of saline water in coastal parts.

In some countries, there is a sudden human population geometric increase and augmenting industrial activities. They have led to increase in potable water demand in a city without municipal water facilities. This, has affected the long term freshwater and saltwater balance in the region. Oteri & Atolagbe (2003) accepted there should be proper freshwater and saltwater interface mapping in the coastal aquifers, and the study to be designed with baseline information on saltwater and freshwater horizons to construct the shallow groundwater physical character in the area. The saltwater into the coastal aquifer intrusion occurs only in densely populated coastal regions (Adepelumi *et al*., 2009) [2]. The work should be done taking into account the baseline data of seawater and assessment of environmental impact to evaluate the need when the coastal population is highly increased (Ayolabi *et al*., 2013) [3].

Limitations

Near agricultural regions, there are always the chances of pesticides and fertilizers presence utilized for the agriculture purpose to percolate through the dry and unsaturated region to reach the strata of the groundwater table. Further, in the case of developing countries, the wastewater disposal is inappropriately done on the surface lacking proper drainage arrangement. That can lead to groundwater contamination. Managed aquifer recharge (MAR) process is used to add and fill aquifers with water under defined conditions to withdraw water at a later stage, or basically used to create a barrier to further prevent other contaminants and the seawater from inward bound water towards aquifer.

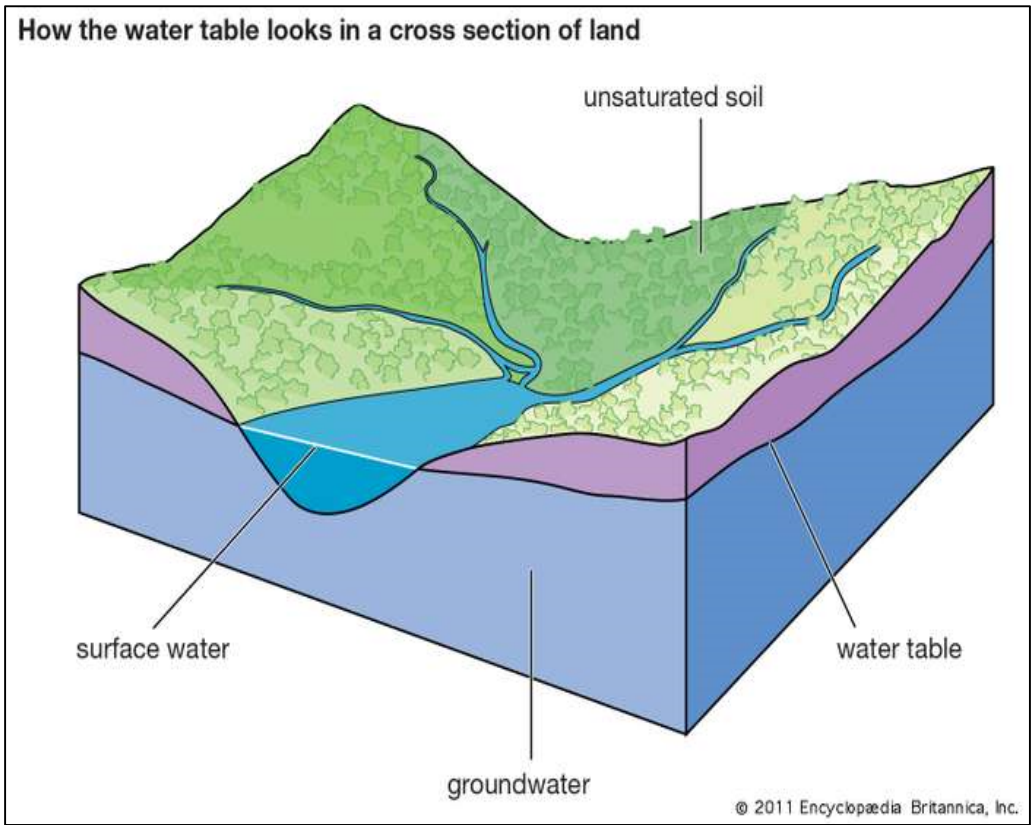
Thus, selecting the MAR location for the recharge process should be taken into account considering the negative factors and properly implement the system for the society benefit. Surface water always contains nutrients, microorganisms, soil particles, and several pollutants, which infiltrate through MAR into the aquifer. Apart from the stored water quality problem, the polluted water infiltration can lead to clogging, and blockage of the aquifer well screens near the structure of MAR. The process of biological clogging create a large impact to reduce e on the aquifer flow and conductivity while making use of untreated water from the surface of infiltration. Inorganic and organic suspended materials and particles of clay and silt adsorption can get accumulated (Raicy, *et al*., 2012) [28].

It is not possible to predict the exact impact of MAR on the conditions of groundwater, but the people access this quality of water for all purposes, in some specific areas.

Conclusion and Discussion

The methods and causes of sea water and groundwater Interference location is very difficult to identify and mitigate where several measures and aspects of seawater intrusion are elaborated in this review paper.

Groundwater observed below the Earth's surface occupies all the parts of the available void spaces in geologic strata and soils. This is also known as subsurface water to identify differences from surface water, observed in large lakes and ocean bodies, which eventually low overland in the form of streams. The surface as well as subsurface water generates the Water Cycle or the Hydrologic Cycle, a constant Earth to the atmosphere, the water circulation by natural systems (Encyclopedia Britannica, 2020) [33].



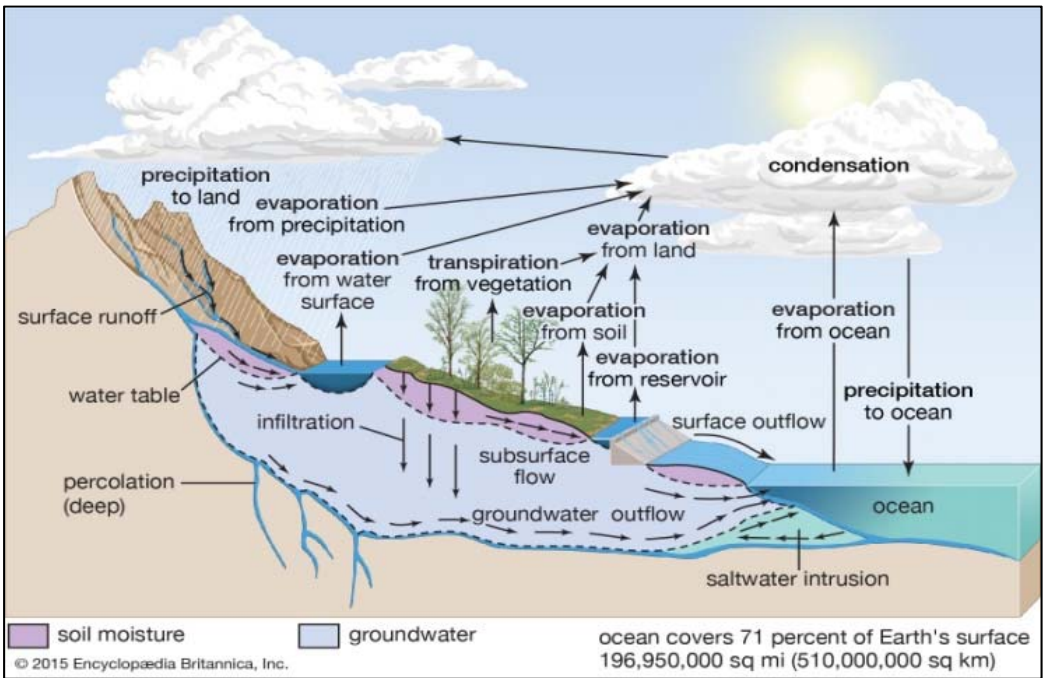


Fig 11: Water Cycle or Hydrologic Cycle, water gets transferred from the ocean, land surface, and the atmosphere.

The water table remains at the groundwater top level, and Surface water is a part of the water table (Encyclopedia Britannica, 2020) [33].

All the groundwater arrives out of precipitation process, wherein the water infiltrates into the soil zone of ground surface. After complete saturation of the soil zone, water starts percolating downward. Hence, a saturation zone occurs when all the intervening spaces, the interstices are completely filled with outside water. Further, the aeration zone is developed where the entire interstices get filled partially by air and mostly by water. The groundwater constantly descends until, it gets merged into a dense rocky zone at a certain depth. Water remains in the rock pores, however, because the unconnected pores, water fail to migrate. The precipitation process with the groundwater replenishing is called recharge. Otherwise, proper recharge happens in the tropical climate,

during rainy, drizzling season, in winter climates. Classically, 15 to 25 % of the water precipitation falling on the Earth percolates the water-bearing underground strata, also called aquifers (Adam Augustyn, 2020) [1].

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