IMPROVING STRATEGIC GROUNDWATER RESERVES IN UAE VIA MANAGED AQUIFER RECHARGE WITH RECYCLED WATER

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Abstract

In this study, we attempt to identify zones suitable for artificial-recharge in Abu Dhabi using (GIS). The solution has started by employing least cost analysis to produce two cost-impact parameters for expected pollution originating from septic tanks and pesticides. Data used includes hydraulic gradient and distribution map of source point pollutions. Cost analysis considered the hydraulic gradient as a friction layer to calculate the accumulative cost-impact over the whole basin and it produces a mapping of high/low cost layers. The high hydraulic gradient is considered the low cost for pollution associated with groundwater. Next, multi criteria of Fuzzy Overlay GIS technique have been introducing in order to integrate the producing cost impact parameters together with Hydro-geomorphic and geologic Indexes based on Analytical Hierarchy Process (AHP) to finally develop Suitability mapping showing the best choice for sites adapted for artificial recharge. The cartography of the groundwater pollution potential, combined to the repartition of favourable zones to artificial recharge, constitute a unique tool to decision making.

Keywords: Artificial Recharge, Least Cost Analysis, Geospatial Mapping, Fuzzy Overlay, GIS.

Introduction

Groundwater is the main source of freshwater in arid regions. Arid regions are known for low rainfall, high potential evapotranspiration, and high intensity/low frequency seasonal rainfall events. The dramatic increase of population and the rapid development in the agriculture and industrial sectors put a huge stress on this already scarce natural resource (Mohamed and Almualla 2010a and b). The average annual groundwater recharge is about 4,875 Mm³. The contribution of groundwater to the total water usage in the region is more than 75% (Dawoud et al. 2005).

Groundwater resources in UAE can be divided into renewable (shallow aquifers) and non-renewable resources (deep aquifers) (Elmahdy and Mohamed, 2012 and 2013a and b). The renewable water resources occur mostly in shallow alluvial aquifers formed by percolating rainfall (Sherif et al., 2011 a and b). On the other hand, the non-renewable deep groundwater aquifers were formed during two ancient wet periods (6000-9000 and 25,000-30,000 years ago) (Wood and Imes 1995). The recharge of shallow aquifers depends mainly on rainfall events and surface runoff, and thus may vary considerably from year to year. Due to the high evaporation rate and surface water runoff in mountains areas, only 10 to 14 % of the total precipitation percolates to recharge the shallow groundwater aquifers in UAE (ESCWA 2003). Yet, many groundwater aquifers in GCC countries are being mined in an uncontrolled and unplanned manner (Mohamed et al 2010 a and b). Unplanned groundwater mining erodes the economic and social sustainability of the communities that depend on the depleting storage (Dawoud et al. 2005; Elmahdy and Mohamed, 2015).

Reuse of treated wastewater has recently been recognized as one of the dependable resources for water supply in the UAE (Daoud et al., 2005). It is mainly used to support the expansion of gardening and landscaping in the country. The annual increase in the use of treated water for irrigation is about 10% (Alsharhan et al 2001). Previous studies (e.g. Halcrow & Partners 1969; IWACO 1986; Entec 1996; JICA 1986; Sherif et al 2011b; and Elmahdy and Mohamed 2014 a and b) show that the groundwater is one of the strategic resources of freshwater in UAE.

Since most artificial recharge concerns, and therefore research, revolve around primarily preserve or enhance groundwater resources by significantly increase the sustainable yield, improve the quality of contaminated or saline aquifers, and others which are environmentally attractive, particularly in arid regions, to prove to its importance that these have been greatly discussed with details than other environmental issue. Certainly, the demand curve that shifts progressively by influence of the factor of number of potential users is resulting with the increase of quantity demanded. In conclusion, many nations which are increasingly acted upon population growth, declining groundwater reserves, contaminated aquifers, and any environmental degradation underlying to Global warming and concerns of water supply security. In accordance with such challenging situation, the search for new solutions is also being pushed by research and experimental design processes along with testing innovative ways to stretch current water supplies and in some cases tap into new sources of supply.

Artificial recharge (AR) is an approach of tapping new water, by its concept is to deposit or direct the excess water into existing groundwater aquifers during the wet season (typically winter months, when surface-water supply exceeds demand) or during the process of reuse of non-conventional water, and then withdraw it during dry demanding spells. Artificial recharge (sometimes called planned recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage. This approach, also, known as aquifer storage and recovery (ASR) (Committee on Ground Water Recharge, 1994).

Detection of an appropriate artificial recharge site of groundwater is a critical step where it should be based on multi geomorphological criteria to meet locations which possess sufficient storage capacity and conductivity, non-permeable continues layers should not be exist between the surface and aquifer, and of locations that have not notable extent of soluble salts so it does not decrease the water quality (Mahdavi et al. 2004). The criteria, its factors and techniques of detecting site-specific mechanism for artificial-recharge were discussed by Ramaswamy and Anbazhagan (1997). Bouwer (1999, 2002) also has pointed out major factors to be considered, and discussed different artificial recharge systems, their design and management.

Factors controlling the implementation of Artificial Recharge studies that have been tested through different research work are cantered as geological description, land use and land cover, soil types, morphology of the area, climate, slope of land, Groundwater water level. All noted parameters are giving the clues on the recharge potential of any location. Recharge potential, is a primary indicator for the promotion of artificial recharge. Based on the surface and subsurface parameters, the recharge potential of any location can be found out using the effective tools of Geospatial Analysis techniques.

In the United Arab Emirates, Abu Dhabi has long dealt with challenges imposed by climate, further to that, it is now facing increased rates of water consumption in order to meet the needs of adding population and those of performing the country economy and urban growth (Dawoud, et al. 2005). Artificial recharge has recently gained much consideration in the UAE. Since Abu Dhabi Emirate relay mainly on the desalinated seawater/brackish groundwater as main sources for domestic supply where huge quantities of drinking water are produced in the desalination plants along the coastline of Abu Dhabi (Black, 2008). Far to the east from Abu Dhabi coastline, where Al-Ain basin is considered an important hydrogeological reservoir that occupies the intermediate drainage area of a regional drainage system originating in north Oman Mountains. Since the reservoir has high potentials for water storativity and also as able to constitute that capacity of water storage for seasons, Al-Ain Basin is selected throughout this study for investigation on the suitability where is the optimum site lying for applications of Artificial Recharge.

GIS Analysis

In establishing an artificial recharge scheme, site selection is the prime prerequisite and its success depends on the collection and analysis of a great deal of geological and geomorphological data geographically (Mehrian, M, 2012). GIS, Geographic Information System has emerged as a useful tool for watershed characterization, conservation, planning and management in recent times. Geographic Information systems (GIS) can be employed to identify the regions of good potential for Artificial recharge in the region, some enterprises has been done in this regard utilizing GIS tools (Ramaswamy and Anbazhagan, 1997; Shankar and Mohan, 2005; Mahdavi, et al, 2013, 2004; Mehrian, 2012; Ghayoumian, et al. 2006; Duraiswami, 2007).

Involvement among GIS as a technology of geospatial analysis for natural resource survey and within the application of Artificial Recharge, multi criteria of **Fuzzy Overlay** GIS technique was exposed by

many researchers to catch with multi-criteria based solutions. But, In contrast, the presence of a closed septic tank or landfill, however, will restrict the area that may be used for artificial recharge because of its high potential for ground-water contamination. Thus, the use of referenced information on the pollution potentials in the area would be looking more integrated in the site selection decision making. **Least Cost analysis** technique; is a GIS practical and geometric planning method which is able to produce mapping of impact on expected groundwater pollution, it analyses the space of any spatial system and calculate its capacity of travelling pollutants.

Combining cost impact layers together with the geomorphological factors through multi-criteria Fuzzy Overlay should earn with precise results (decisions) for artificial recharge site selection. GIS tools again will employ the concept of **Analytical Hierarchy Process** (AHP) to have come with this combination. AHP is a technique of most common driver that scales the multi factors and stretches all its perspectives (trends) into one unique baseline for final comparisons.

In this study, we are going to identify zones suitable for artificial-recharge in the eastern of Abu Dhabi Emirates using improved approach, which utilizes Identification of the Cost Impact that causes pollution on aquifers and integrate them as constraint with other geologic, morphologic and climatic factors throughout (Multi criteria of Fuzzy Overlay GIS technique) and Analytical Hierarchy Process (AHP) in order to draw decisions towards optimum groundwater recovery system.

Study Area

The study area falling to the northeast of Abu Dhabi Emirate is called the North-Eastern Region or "Al Ain Basin" (Brook, 2005). Lies between latitudes 23°56'07" and 24°48'58" N, and longitudes 54°56' and 56°01' E (Figure 1). It covers an area of about 6320 km^2, Al Ain Basin contains aquifers are Quaternary sands and gravels, which continues eastwards into neighbouring Oman. The source of the fresh ground water in the Eastern Region was primarily underflow through the alluvial sediments in wadis that drained the Oman Mountains and episodic storm runoff concentrated in the wadis.
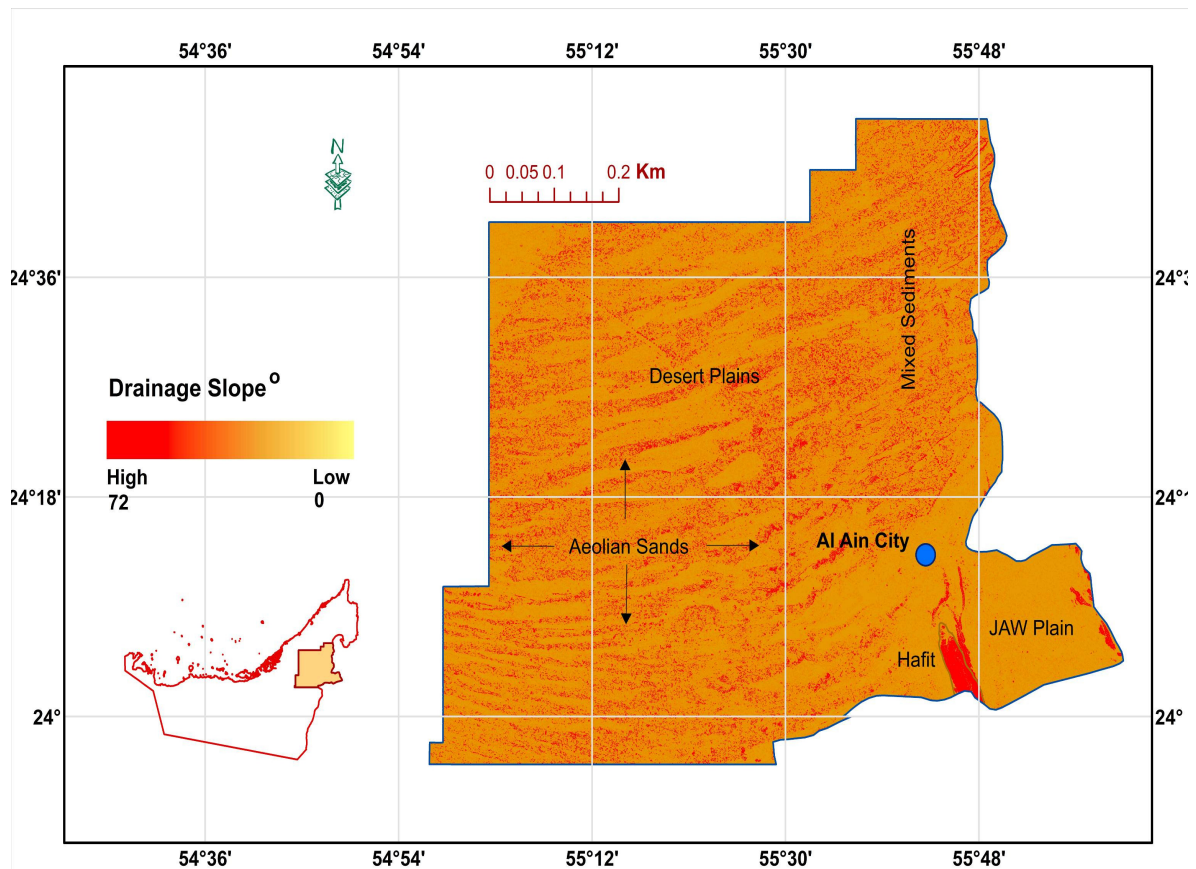
Figure 1. Location map of Study Area

Factors Controlling the Recharge Zones

Various factors, which are the controlling or the contributing parameters of groundwater recharge suitableness, these are considered in our study area are described as in the following:

Rainfall: The area enjoys arid climate with very hot summer and moderately cold winter, the maximum and the minimum temperatures being 45°C in June and 4°C in January. Mean annual rainfall for the Eastern Region, varies between 80-100mm/yr. The mean annual, rainfall at Al Ain 1971-1994 is 96.4 mm with a maximum of 303 mm/yr. (Figure 2b). The average annual runoff depth for the 1981-1991 period ranges from 5 mm in southwest Al Ain, to 20 mm in the northeast (Brook, 2005). Rainfall in the Al Ain area, this gradually declining as one goes west and south.

Water Level: The water table in the surficial shallow aquifer system generally slopes westward from a high between 260 and 360 meters above sea level at the Sultanate of Oman-Abu Dhabi Emirate boundary north of Al Ain. The average westward gradient, based on 100 meters of head change over 25 kilometres of distance is 0.004 (Figure 2a). The average saturated thickness of the surficial aquifer system is about 75 meters and the overlying unsaturated zone is between 25 and 50 meters thick. Three areas north, west, and southeast of Al Ain had severe water-table declines of more than 10 meters between 1990 and 1995. (Hutchinson, 1998).

Soils: The soils of Abu Dhabi Emirate according to (Shahid and Abdelfattah, 2005) can broadly be categorized as sandy, sand-dune, sandy calcareous, gypsiferous, saline, saline-gypsiferous, and hard pan soils. These soils have been classified under three soil orders (Aridisols, Entisols and Inceptisols) of the Soil Taxonomy (USDA-NRCS, 1999). The predominant soil types are: (1) the coarse gravel and sand in the piedmont and alluvial plains to the east of Jabel Hafit; (2) the sandy soil to the west of Jabel Hafit in the north and south sand dune area; and (3) the bare bedrock in the mountain areas in Oman and Jabel Hafit (Figure 3.a) (Al-Zabet, 2002).

Geology / Morphology: Its geomorphic units are classified by several provinces; Mountains, Gravel Plains, Fluviatile Basins, Sand Dunes, Inter-Dune areas and Inland Sabkhas (Figure 1) (Abou El-Enin, 1993; Al-Shamsei, 1993; and Baghdady, 1998). Most of Al- Ain area is covered by quaternary deposits that consist of alluvial and aeolian origins, together with significant extent of desert plains in the north-west in addition, there are inland sabkhas towards the coastlines (Hunting, 1979 and Abou El Enin, 1993).

Land Use: In the Eastern Region, around Al Ain, a different pattern applies. Broad levels of land use have been recorded including urban or built up land subtends to the north of Jabal Hafit with area of km^2, farming and agriculture is practiced from East to West in a line in areas where groundwater level is shallow, rangeland or grazing lands which are very common in the gravel plains like "Jaww plain" and fluviatile deposits, Oasis and Forestry wooded parklands are considered water abundant lands where it constitutes as a dense and woody cover. In the desert areas the dunes, these will be primarily related to the grazing of livestock varying according to the amount of rainfall (Figure 3b) (State of the Environment Report, 2006).

Analytical Hierarchy Process: Weighting and Ranking

AHP is a technique of most common driver that scales the multi factors and stretches all its perspectives (trends) into one unique baseline for final comparisons. It converts individual preferences into ratio scale weights that can be combined into a linear additive weight w(a) for each alternative (Forman and Gass, 2001). The resultant w(a) can be used to compare and rank the alternatives and, hence, assist the decision process for making a true choice where to be applied is most suitable for artificial recharge.
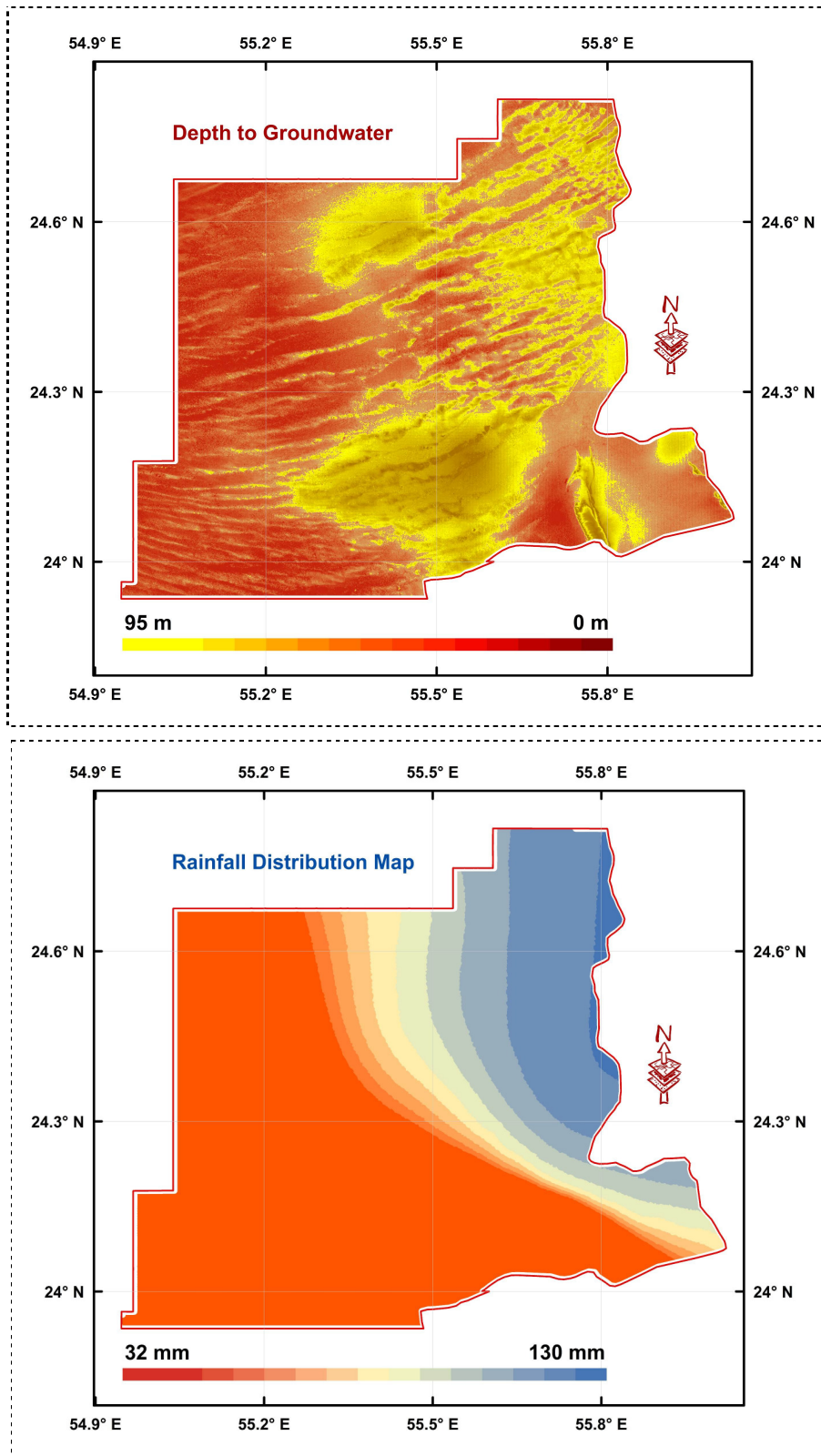
Figure 2. Factors Controlling the Recharge Zones (a) Depth to Groundwater. (b) Rainfall Distribution.
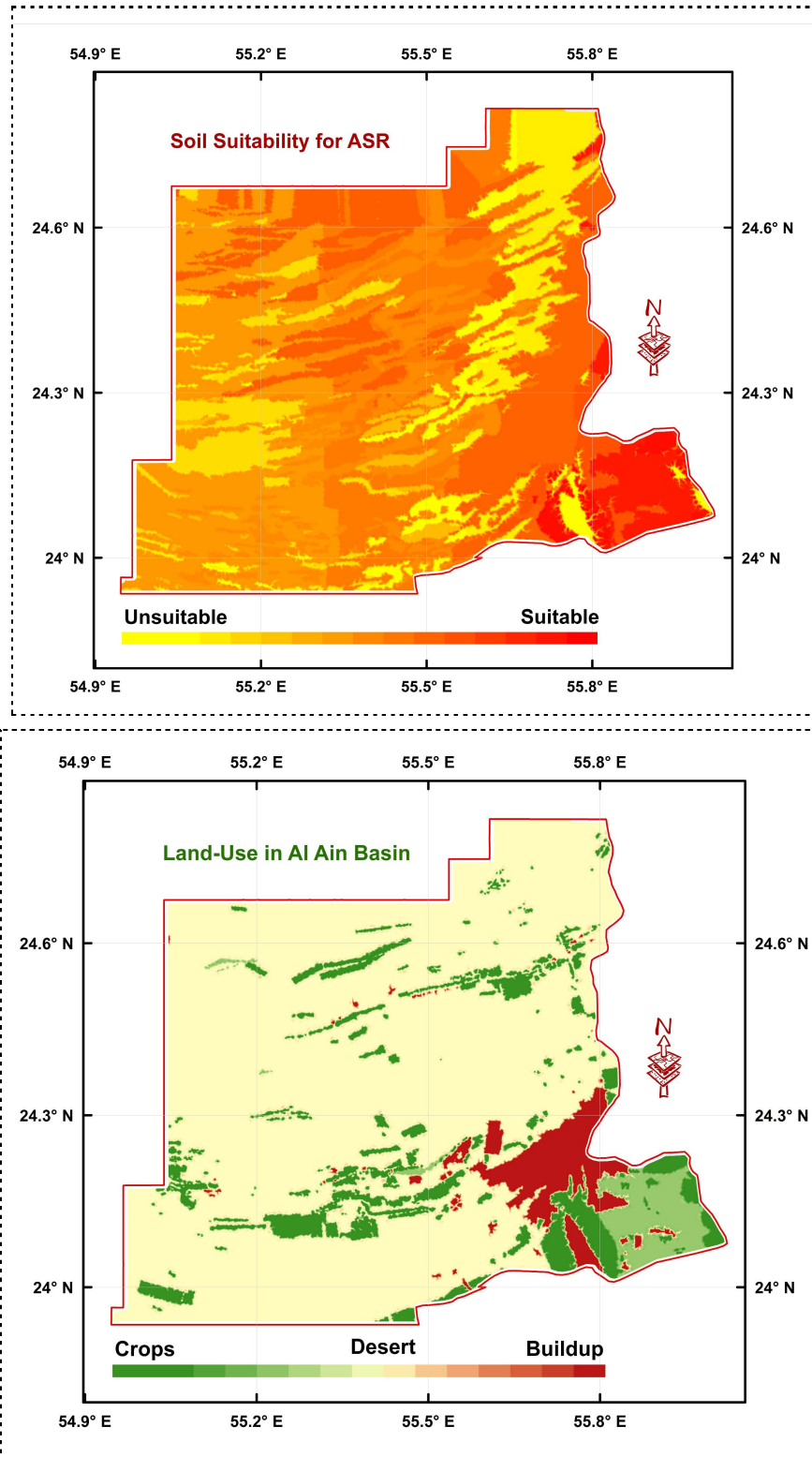
Figure 3. Factors Controlling the Recharge Zones (a) Soil Suitability for ASR. (b) Land Use Distribution.

The different units in each theme are assigned a knowledge-based hierarchy of ranking from 1 – 5 (Table 1). These were assigned on the basis of their significance with reference to their influence on identification of groundwater artificial recharge sites. In this ranking 1 denotes poorly favourable zone, while 5 denotes to a very good zone.

Table 1. Ranks and their Influences on identifying artificial recharge sites

Ranks	Influence for identifying artificial recharge sites
5	Very good
4	Good
3	Moderate to Good
2	Moderate
1	Poor

Various thematic maps of previous controlling factors are reclassified using GIS-AHP, and the weight influence and rank for each class is given in the following table (Table 2)

Table 2. Influencing Factors, their classes ranks and weights

Parameter	Class	Rank	Wt.	Parameter	Class	Rank	Wt.
Geology	Gravel Plain	4.8	4.5	Rainfall	130 mm	1	2.5
	Desert Plain	4.1			100 mm	1	
	Fluviatile	4.5			70 mm	1	
	Sand Dunes	4.3			40 mm	< 1	
	Limestone and Marl	1			< 10 mm	< 1	
Slope	0 – 1 o	5	3	Storativity	Gravel	4	4
	1 – 3 o	4			Coarse Sand	4.2	
	3 – 7 o	3			Fine Sand	4.5	
	7 – 15 o	2			Silt	5	
	> 15 o	1			Rock	2	
Morphology	Pediment zones	4.75	3.5	Soil	Alluvial Gravels	5	3
	Structural hills	4			Fluviatile sandy soil	4	
	Desert	3			Brown Soils (Desert Sands)	3.5	
	Inter-dune Areas	2.8			Fine sand - Silt	3	
	Mountains	1			Hills (Bare Bedrock)	1	
	Plateau	3 –		Lineamen	Faults Zone	5	3.5
Water Level	< 6 m	1	6	Land Use	Buildup Area	1	3.5
	6.1 – 12 m	2			Agriculture	3.5	
	12.1 – 18 m	3			Rangelands and Grazing lands	2.5 - 3	
	18.1 – 24 m	4			Forestry and wooded parklands	4	
	> 24 m	5			No Vegetation - Rocks	1	

From previous tables, Groundwater level is scoring the highest because it is an indication that water level is harmed by declination due to over-exploited or low rainfall rates. The eastern part of Al Ain basin is showing low levels of GW where intensive water use is taking place, furthermore, is considered that morphological divide of the Basin where the subsurface discharge is starting towards the West and South-West in a common drainage direction. One thing, when looking to geology, we find that majority of the basin constitutes Alluvium deposits, accordingly our consideration in geology classes will be more sensible, but the other factors like slope that varies much between the East and the West will be more deciding for site selection process.

GIS Fuzzy Overlay

GIS multi-criteria evaluation can combine a set of factors in order to resolve their differing perspectives into a single solution; this considered a resource allocation decision (J R Eastman, 2005) which is worthful approach in decision making process.

GIS-Fuzzy has been used for the integration of previous thematic factors to delineate the potential zones for artificial recharge. Each theme was assigned a weightage depending on its influence on groundwater recharge. Each class or unit in the map was assigned a knowledge based ranking from one to five depending on its significance in storage and transmittance of groundwater. The most common application for Overlay tools is suitability modelling, the factors were multiplied by the appropriate multiplier (Scores or Weights), and for each cell, the resulting values are added together. Weighted Overlay assumes that more favourable factors result in the higher values in the output raster, therefore identifying these locations as being the best. In the following is the resultant principal mapping for suitability to initializing ASR projects (Figure 4).The final map has been prepared showing different categories of land suitability for applications of artificial recharge (Figure 4).
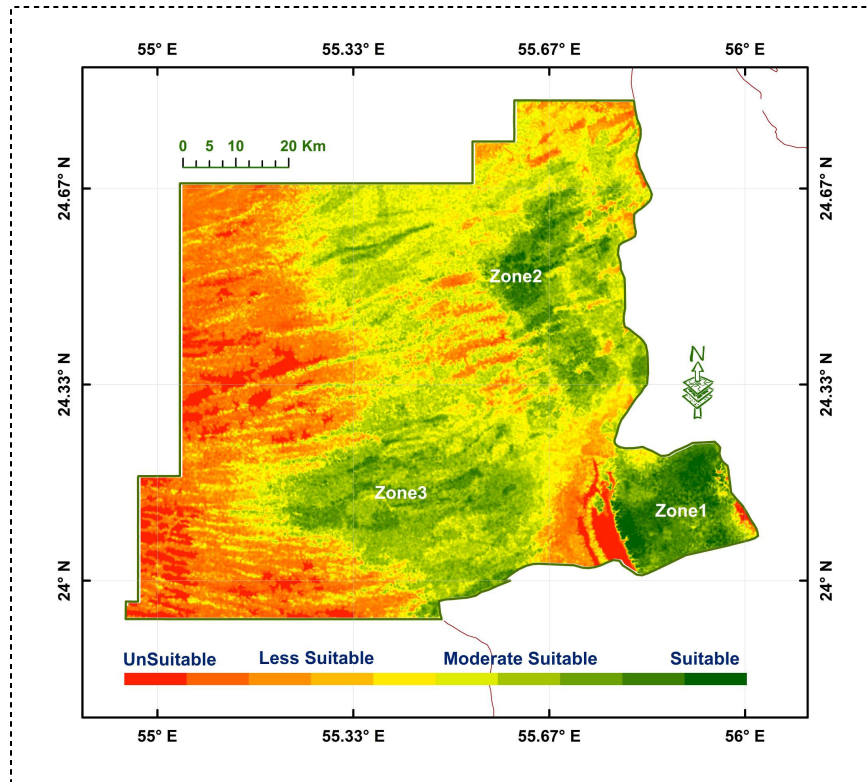
Figure 4. Principal Mapping For ASR Site Selection

Belonging to the map above, four different distinguished colours are representing four areas in the whole basin, which some are full of suitability and some are very poor suitable lands.. Green is very suitable, Yellow is moderate, Orange is less suitable and Red is poor indication as Unsuitable. Areas that have good suitability are being located in three zones of involvement.

Zone1: is Jaw plain, that involves a gravel and sand sediments which have characteristics of high storativity and permeability of water (Figure 4), also it is an hydrogeological entity receives good rainfall amount, Jaw plain is subjected to a dynamic hydrogeological process for gravel and sand deposition, by its role it constitutes high thicknesses as shallow aquifer. In addition it is a part of Wadi deposits and there are proofs of main lineaments of gravel outwash sediments. All these reasons make Jaw Plain with good conditions to store more water. **Zone2:** is the North-Eastern part of the basin (Figure 4), to this zone, beside some of previous suitable conditions, it involves an intensive zone of geological structures and lineaments, mainly those are about structural Faults that have dominant direction NW-SE which has been out came as a result of regional constructive forces, these faults are deep and it penetrates through the whole column of the aquifer media. These Faults builds zones of small basins and make larger space for storing extra water. **Zone3:** the area is located in the

middle between alluvial plains to the East and the Dunes (Desert) to the West (Figure 4). This area involves gentle land slopes while water can stagnant for longer time for recharging. It is an area where groundwater level is very low, for the reason that most agricultural activities occurs in that place and groundwater abstraction due to that is over.

Areas of which Unsuitable, involve bad conditions for artificial recharge site selection and it is discovered in two zones, one is wherever groundwater levels are near to the ground surface (High GW table), and it has the potential to form land Sabkhas due to high evaporation rates, these areas experience no sufficient thicknesses and is characterized to have low storativity and permeability, it is considered the discharge zone of Al Ain Basin. Sabkhas can be located far in the West in adjacent to the Basin boundary (Figure 4). The other location while conditions came Unsuitable is Jabal Hafit (Mountain), its area covered by consolidated sedimentary rocks of limestone and marl where recharge potential is very low. Furthermore, the area regarded as very composite of steep slopes and water never have chance to be stored in subsurface layers (Figure 4).

Least Cost Analysis: An Improved Methodology for Site Selections

Groundwater crisis is not the result of natural factors; it has been caused by human actions. In this methodology we are going to refine and improve our results for the above Suitability Mapping by considering two new controlling factors that can give idea on a continuous and non-point source of pollution. Once the impact is delineated in areas that meet high suitability for artificial recharge, then more considerations should be taken to decide unlike to our earlier choice. Therefore, Least Cost analysis technique; is a GIS practical and geometric planning method which is able to produce mapping for impact of expected groundwater pollution; it analyses the space of any spatial system and calculate its capacity of travelling pollutants. Its algorithm utilizes the node/link cell representation used in graph theory to calculate cost per unit distance for moving through the cell, it uses some kind of physical friction data that is controlling the way that associated pollution is linking between the surface and Groundwater aquifers. In our case, we are targeting to make Cost-Risk mapping about expected pollution from two non-point pollution sources. Points represent poorly designed septic tanks and other points represent intensive pesticides usage (Figure 5), the whole pattern in the basin is then analysed utilizing Hydraulic Gradient as a friction parameter (Figure 5), in order to tell; what is cost that Hydraulic Gradient corresponds in each cell for moving such risks (septic tanks and pesticides use).
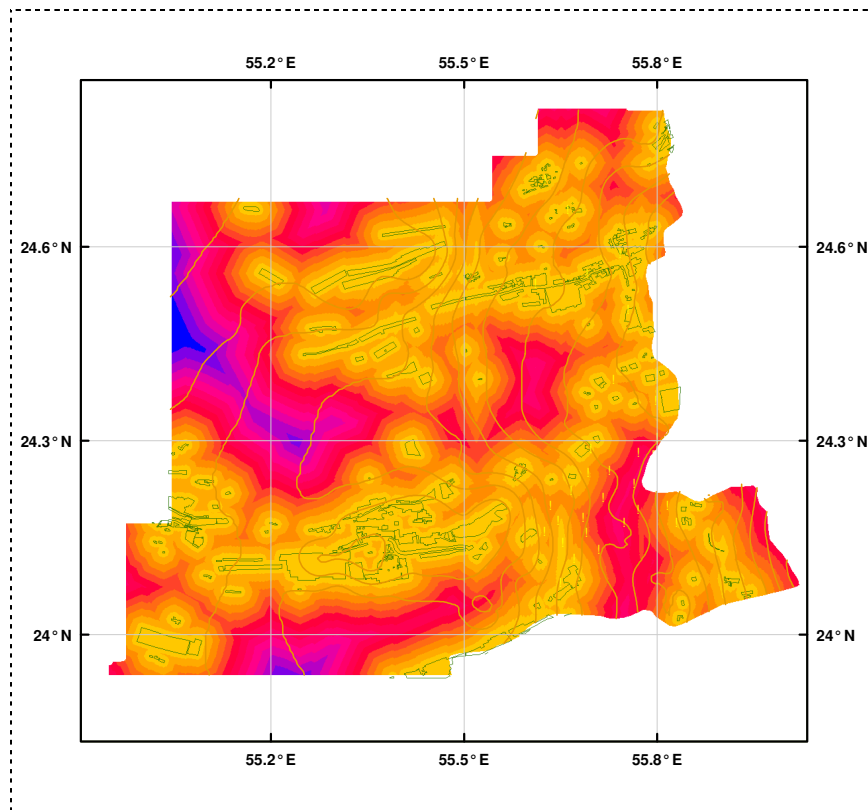

Figure 5. Cost Impact Mapping

Figure 5 shows the resultant cost impact layers; these will be carried as additional influencing factors to improve making our decisions for site selection, the cells that have low cost considered high risky (Red Coloured Cells) whenever pollutants easily travel in the basin through paths which hydraulic gradient makes (Figure 5). Cells of low cost will have negative behaviour on the site selection process. In Table 3 by Using AHP, Rates and Weights have been drawn for cost impact factors in purpose for later integration, the score that cost impact factors have is four which is unbiased value of its influence than others, that equals the average of all scores have ranked before.

Table 3. Cost Impact Factors, their classes ranks and weights

Parameter	Parameter	Class	Rank	Class	Weight
Cost Impact – Pesticides Use	Cost Impact – Septic Tanks		1	No Cost – High Risk	4
			2	Low Cost – Risky	
			3	Moderate	
			4	Become Costly – Low Risk	
			5	High Cost – No Risk	

For final combination and integration, Fuzzy overlay has been performed again considering the new cost impacts factors. Resultant and improved mapping of land suitability for artificial recharge site selection is shown in the following (Figure 6):
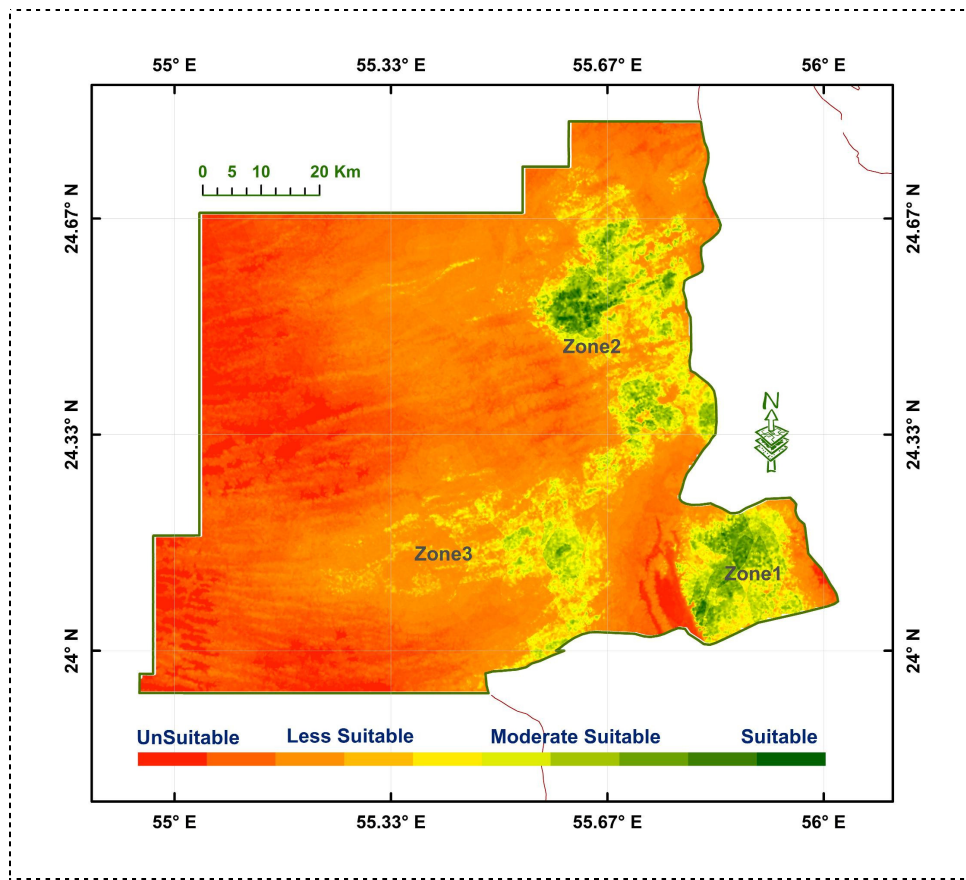
Figure 6. Improved Mapping for ASR Site Selection

From map of improved approach (Figure 6), it is obvious that areas were having high suitability are become smaller than before, the extent has been restricted to a limited and particular zones. But, those three zones which had good conditions in the earlier result are still of the same involvement. Concluded, we have found that areas of high suitability have been reduced by around 65 % present. This new mapping raises reasoning about how one(s) of likely suitable lands is becoming shortened in that shape and mechanism. For zone 1, in Jaw plain, green areas appear with the new distribution of suitability that take their extent by NE-SW, it represents a zone of which contamination is out of association to these lands. In other extent of yellow coloured areas, their lands are partially connected to risks and it is considered moderate suitable. Lands far in the east at the start of Jaw plain are classified less suitable and has poor conditions, the regarded zone has orange/red coloured area (Figure 6), and it constitutes very coarse gravel sediments that can permit the fast flashing for water, its high capacity to discharge water makes this zone as sink area from surrounding parts of the aquifer.

In zone 2, to the North-East side of the basin, areas of good artificial recharge suitability are not reduced much, rather, we notice that its area has been separated into two parts, one lie in the north and another in the south (Figure 6), the division zone located in between is crossing the same extent of areas which have high risk in the map of cost-impact analysis, therefore the area has been eliminated and is now occupied by lands of less suitability for applications of artificial recharge. zone 3 is becoming mostly carried off from good suitability, to the east of zone3, only a small area which stays with good conditions (Figure 6). This could be handled where the intensive agricultural activities are overlapping this zone, by which, the pesticide use is high and forms the required risk to decide that initialization of artificial recovery projects is not suitable in these lands.

In the principal Suitability mapping, areas which are unsuitable are remained unsuitable later - in the improved approach. So, a purpose to have identifying the lands which without doubt are considered unsuitable for application of artificial recharge would be experienced adequately through only the utilization of principal suitability mapping.

CONCLUSIONS

In this study, an optimum methodology of site selection for managed aquifer recharge is applied Alain city in Abu Dhabi. Al Ain basin has high potentials for establishing such projects in alluvium aquifers in the basin that have sufficient capacities to store additional water. GIS has been used in this paper as a useful tool for representing, weighting, ranking and combining multi-factors that are controlling the decisions on site selection. In order to identify the best sites several factors were considered in the multi-criteria based evaluation processes for site selection. Least cost impact analysis is proven to be helpful approach in decision making process for the selection of the optimum site to be selected.

ACKNOWLEGEMENT

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