The impact of urban growth on ground water salinity rates on the Lebanese coast

N. Fayssal[1] & K. Slim[2]
[1]Department of Environmental Geography, Lebanese University, Lebanon
[2]Lebanese Atomic Energy Commission, National Council for Scientific Research, Lebanon

Abstract

For the purpose of monitoring the seawater intrusion on the Lebanese coast, a selected region south of Beirut – Chouf coastal region from Naemeh to Remaileh – was chosen to be studied. The region is witnessing an urban sprawl since the nineties and the water supply by the government water network is insufficient to meet this increase in the demand due to fluctuation in surface water availability affected by climate change. This enhanced the dependence on the underground water to be the only source of water in many sites where it is used for multiple purposes (agriculture, domestic and sometimes portable). 32 wells were chosen at different distances from the shore in order to track the extent of water intrusion into the underground water. Water samples were collected three times during the year, at a rate of one sample each 4 months, between wet season (spring 2014) and dry season (fall 2014). The collected water was tested for electric conductivity, TDS and chloride in order to evaluate their salinity status. The results obtained from the study showed that the sea water intrusion that was recorded during the 1980s in some sites extends to most aquifers of the entire region now. In comparison with old studies, salinity levels were doubled or tripled in certain tracked wells. Also the results showed that in a strip area of 1 km all along the shore, water wells have salinity rates between 1.5 ds/m and 5 ds/m (the majority being 3.4 ds/m during the wet season and 5 ds/m during dry season). These values are alarming in an agricultural area depending mostly on wells in their crop production with an expected increase in water demand for domestic use.
Keywords: underground water, seawater intrusion, salinity, Lebanese coast, water stress.

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1 Introduction

Urbanization is a major change taking place globally. The urban global tipping point was reached in 2007 when for the first time in history over half of the world's population 3.3 billion people were living in urban areas. It is estimated that a further 500 million people will be urbanized in the next five years and projections indicate that 60% of the world's population will be urbanized by 2030.This rush to the cities, caused by the attraction of opportunities for wealth generation and economic development resulted in the cities expansion beyond its borders (Freire [1], WB [2]).

This incredibly rapid urbanization has severe ecological, economical and social problems. It is increasingly difficult to manage this growth in a sustainable way. It is recognized that over 70% of the growth currently takes place outside the formal planning (WB [2]).

In developed countries impacts of the urban growth are less severity than those in third world countries. urban planning, zoning, prediction of water demand and finding the sources of supply, sewage systems and treatment plants, green areas, recreation space, biodiversity prevention measures and other measures are taken into consideration to accompany the expansion of urban areas in the countries of the north (Freire [1]).

Developing countries and third world will continue to see increasing rates of urbanization more rapidly than developed countries, without real effort for improving the urban planning strategies. This has its environmental, social and economic impact and will increase the pressure on the natural resources (WB [2]).

As previously mentioned, most cities are expanding beyond their administrative boundaries, and this is the case of Beirut which expanded to be great Beirut area in the last three decades without any planning (MOE [3]). Of course the Lebanese war has the greatest role in this mess in urban expansion even due to illegal buildings and administrative corruption, or to the bad zoning strategies implemented and not updated continuously. Urban planning and zoning of the Lebanese territories was first prepared in the 1960s. Due to the Lebanese civil war, the urban planning was not updated for more than 40 years, until 2004 (CDR [4]). During this period Beirut witnessed a messy urban expansion in all directions causing the northern and eastern regions surrounding Beirut to be highly urbanized. The most recent master plan for organizing the Lebanese territories was prepared in 2005. This master plan indicated to the fact that the future expansion of the capital will be oriented towards the southern region adjacent to the greater Beirut area, which is the studied region (CDR [4]).

2 Region description

The studied area is located south of Beirut and it extends along the coast of the Chouf region. It occupies 20 km of coast and a width ranging between 1.7 and 3.2 km. This region is bordered by the greater Beirut area from the north, and by Saida from the south. Saida is one of the Lebanese big cities, known as the capital of the south and is expected also to expand beyond its borders, especially in the northern direction (CDR [4]).

The region constitutes a coastal plain that slopes down from east to west, wide in the northern part, forming a big cultivated area and completes narrow and discontinuous in the middle and southern part (figure 1). The elevated part of the region is reaches 300 m above sea level sloping down gently from east to west. It merges to the sea in some localities forming escarpments and heads where 10 submarine springs were detected (MOE [3]). There are 12 valleys running from east to west. Most of the valleys in the study area except Damour River, expect seasonal stream flow during rainy seasons only.

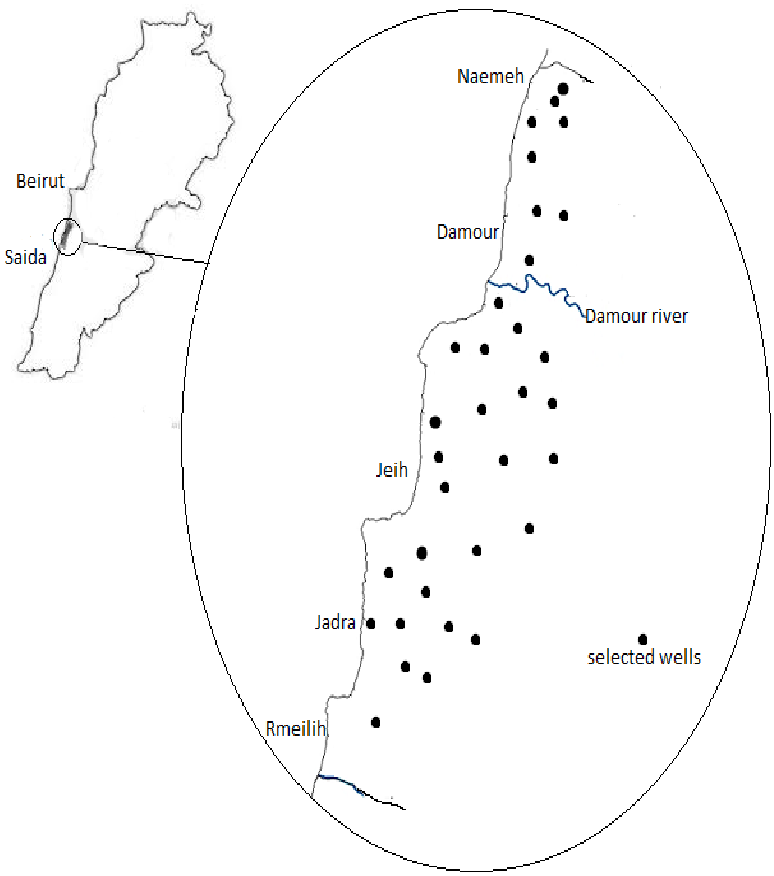

Figure 1: Studied area and the selected wells.

All the outcropping formation in the region belongs to the upper and middle cretaceous except for the superficial valley deposits and the coastal deposits which are Quaternary and Holocene. The Cenomanian-Turonian (C4-5) outcrops in 80% of the study area and along the coastal ribbons. Senonian (C6) occupies 13% of the area and the upper Jurassic Portlandian (J7) and the Quaternary Deposits (Q) occupies the rest (Awad [5], Arkadan [6]).

This Cenomanian-Turonian aquifer – Sannine aquifer (local name) – is desiccated by parallel NE–SW faults. The aquifer is of secondary porosity causing ground water to flow mainly through fractures, joints and channels, which is the characteristic of karstic aquifers. The karstic features like caves are abundant (10 karsts caves) in the area together with faults reveals the richness of the area with underground water (Awad [5], Arkadan [6], Shaaban [7]).

3 Urbanization and water availability

Added to the impact of urbanization on morphologic elements of the nature, it has the greatest impact on the water availability. This region which is the destination of displacement of citizens from the three different directions – two cities on the northern and southern borders and semi-rural villages to the east – witnessed demographic growth that exceeds 30% in the last two decades. The region is now inhibited by more than 200,000 people (this data is obtained from direct interviews with local authorities due to lack in governments' statistics).

This rapid urban expansion started during the 1990s in the era followed the Lebanese civil war. At that time, governments focus was more directed towards political issues, and the urbanization was taking place outside any integrated urban planning to maintain sustainable development. This expansion was not associated with the allocation of a sufficient quantity water to meet the increasing demand on water or develop new sewage discharge networks. This ended with the fact that, water supply from government water-networks covers only 38% of the population during eight months – between November and June – and 28% during the remaining four months (data gathered from the Beirut and Mount Lebanon water authority). Also, it is worth noting here that 60% of urbanized areas depend on septic tanks for their sewage discharge, knowing that most of these tanks are non-conforming to the international environmental standards.

Until 1991, about 90 wells were drilled in this region. This number started to increase gradually with urban expansion, especially in new residential areas which were introduced in the outskirts of the villages. The wells in this region were, historically, mostly drilled for agricultural purposes or supportive sources of water during dry season. Underground water is now the main source of water for irrigation in this area, due to the decrease of surface water availability in Damour River in the dry season (historically part of the river was diverted for irrigating the northern plain of the area). The pumped water is also the main source of water for domestic use of more than 62% of the current residents, added to it supportive role other 10% during the dry season, when water supply from government water works is not sufficient.

Due to the abundance of illegal private wells, it was difficult to find the exact number of current drilled wells in this region. By matching data from different sources, the study could estimate the current number of drilled wells to be about 600 wells, of which 40% are licensed as estimated by local authorities (Awad [5], Arkadan [6], ARD [8]).

4 Methodology

Wells selection: 32 wells were selected in a manner to cover urbanized areas with different densities and agricultural areas. They were also selected at different distances from the shore ranging between 0.1 and 2.5 km. At 32 locations sampling took place three times with a 4 month time interval starting in April 2014 presenting wet season and a second sample in July–August and a third in November 2014 in an attempt to monitor the maximum extent that the underground water salinity can reach. Starting from December rainfall starts to replenish the underground water as shown in previous studies (El Moujabber *et al.* [9]). These samples were tested at the Laboratory of the Center of Lebanese atomic energy commission (CNRS) using the conductivity meter WTW LF 90 and pH meter WTW 90.

5 Results

The results showed that in a strip area of 1 km all along the shore, water wells (14 wells) have salinity rates between 1.6 ds/m and 5.8 ds/m during the wet season and the majority exceeded the 3 ds/m of which three wells recorded salinity rates exceeding 5.8 ds/m during dry season.

The 10 wells located between 1 km and 1.5 km, have their salinity rates vary between 0.72 ds/m and 1.48 ds/m during wet season. In most of these wells, salinity rates showed an increase in the salinity rates. Although it is negligible in some sites but it reaches 1.7 ds/m in two wells, during dry season. It is important to note here that salinity rates recorded slight changes, in some sites, because these wells are not exposed to intensive exploitation, being used by a single residential unit.

In the 6 wells located between 1.5 and 2.5 km from the shore the salinity rates recorded were all less than 0.7 ds/m during the wet season and recorded a slight change without exceeding 0.75 ds/m in the dry season. The two control wells which were chosen at 3 km from the shore, kept their salinity rates at about 0.56 ds/m during the wet and the dry season.

The TDS values comes consistent with high salinity rates being all above 360 ppm and reaches 1560 ppm during wet season and recorded high values reaching 2000 ppm during dry season in some sites. The chloride concentrations also go in the same direction with concentrations that exceed 170 mg/l in most wells at distance, 1.5 km from the shore.

6 Discussion

In the eighties and until the early nineties, underground water was considered, in this region, as of good quality and the salinity rates were within the permissible limits of fresh water standards (Awad [5], Arkadan [6]). The EC_w values were less than 1 ds/m and TDS values were less than 400 ppm, in all the area northern

Table 1: Electric conductivity rates recorded in the three sampling intervals.

Distance from the shore	Well number	Electric conductivity of water EC_w (ds/m)		
		Spring sampling	Summer sampling	Fall sampling
Between 0.5–1 km	1	5.28	> 5.80	> 5.80
	2	1.90	2.45	> 5.80
	3	1.61	1.47	1.64
	4	5.54	3.00	3.16
	5	3.27	3.35	3.50
	6	1.72	2.20	2.60
	7	1.92	2.70	3.40
	8	3.20	5.60	3.70
	9	1.83	2.00	3.00
	10	2.90	3.00	3.27
	11	2.80	2.80	2.90
	12	3.50	3.50	3.50
	13	3.50	3.50	3.50
	14	5.80	> 5.80	> 5.80
Between 1–1.5 km	15	1.43	1.71	1.46
	16	1.22	1.22	1.30
	17	1.48	1.70	1.70
	18	0.85	1.38	1.40
	19	0.82	0.90	1.03
	20	0.60	0.92	1.10
	21	0.91	0.91	0.93
	21	0.73	0.75	0.77
	22	0.80	0.80	0.80
	23	0.72	0.74	0.74
	24	0.72	0.72	0.72
Between 1.5–2.5 km	25	0.55	0.57	0.70
	26	0.57	0.66	0.66
	27	0.61	0.66	0.66
	28	0.65	0.65	0.75
	29	0.66	0.69	0.69
	30	0.61	0.66	0.66
3 km	31	0.54	0.55	0.55
	32	0.56	0.56	0.56

Damour River and in all wells at a distance ≥500 m from the shore in the area located south of the river. Noting here, that 0.5 ds/m and 400 ppm are the thresholds of EC_W and TDS respectively, in fresh water. The hydraulic system was at the margin of balance with about 4.5 mm^3 water discharge from wells for domestic and agricultural consumption.

In this study, water discharge from wells for domestic use is estimated to be 10 mm^3 (per capita water demand in Lebanon being 407 m^3/capita/year – FAO statistics). A similar quantity is needed for irrigating about 1600 cultivated hectares, falling within the region (ARD [8]). So we can speak about 20 mm^3 of water pumped from the wells and exceeding natural water balance by 4–5 times.

Salinity of underground water in this region goes, mainly, back to salt water intrusion rather than anthropogenic origin, due to the low sodium/chloride ratio (<1) in the water (El-Moujabber *et al.* [10]). Only wells falling within the Damour River's basin which are replenished continuously by the river's flow and their salinity content is more likely to go back to human activities and the deterioration of the river's water (Saad *et al.* [11] and Massoud [12]). Then the over exploitation of the underground water have resulted in seawater intrusion on wide scale in the studied area, even in the northern part (northern Damour River) which was considered, until 1990s, as protected by impervious cap of Senonian (C6) formation together with the quaternary deposits (Awad [5], ARD [8]). For example, the TDS value was recorded to be 500 ppm (Awad [5]) in 1989 in a well located at a distance 460 m from the shore and now, in this same well, TDS is found to exceed 1200 ppm.

The salinity levels were doubled or tripled in most wells located within 1 km strip area extended along the shore.

The fresh water/sea water interface contour line was lined in 1965 at – 150 m (under sea level) for a strip area that varies between 0.5 and 1.2 km parallel to the shore (Arkadan [6]). As can we see above the salinity rates exceed 0.5 ds/m in the wells, in their best situation, during the wet season at a distance that goes beyond 2.5 km from the shore. This means that this fresh water/ seawater interface has intruded in land more than 2 km.

This deterioration of the underground water is mainly due to over exploitation of the aquifers, but the decrease in precipitation that was recorded in the last 3 decades (figure 2) has its double impact on the aquifers deterioration. Any decrease in the precipitation means a decrease in the surface water availability and consequently increases the pressure on underground water. At the same time, this reduction in the precipitation diminishes the natural replenishing of the aquifers, since rainfall is the major source of the aquifer natural recharge in this area (Shaaban [7]).

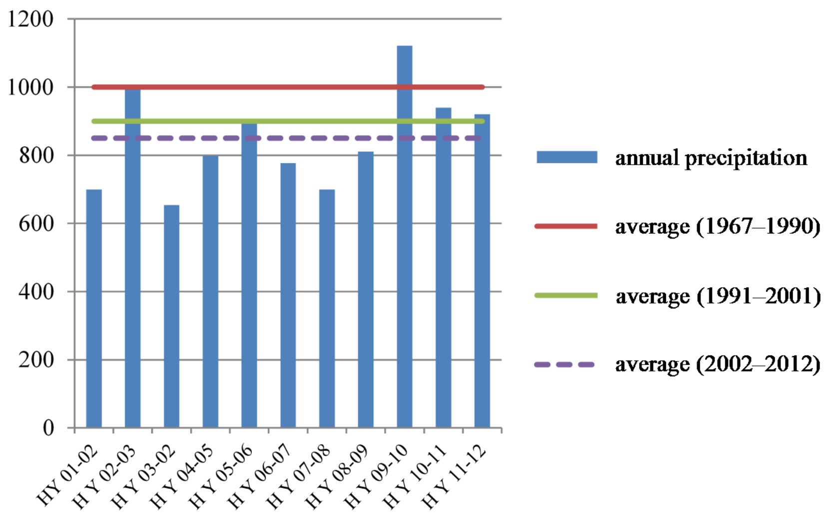

Figure 2: The change in the annual precipitation (mm) in the hydrological years (1967–2012). Source: Meteorological Services Department, Beirut Airport, RHIA.

People's acceptance for the salinity of water in domestic use is not optional, being their only feasible choice, and they rely widely on bottled water for drinking and cooking purposes, but this water can result in excessive scaling in water pipes, heaters, boilers, and household appliances (USBR [13]).

The underground water is the main source of irrigation water for about 30% of the area which is cultivated by different crop types and mainly green leaves vegetables, strawberry, olives, citrus and banana trees. The residues from the applied fertilizers, together with the high salinity rates in the irrigation water, resulted in soil salinity (ECe) ranging between 3.64 ds/m and 28 ds/m (El-Moujabber *et al.* [10], Darwish *et al.* [14]). On the other side, studies showed a significant impact of soil and irrigation water salinity on crop production, with a higher impact on yield than on the plant growth as a whole (Paranychianakis and Chartzoulakis [15]). As we can see in table 2, the soil salinity tolerance of main crops cultivated in the studied area is lower than those detected in the soil. Also, most of these crops have irrigation water salinity tolerance lower than 1.7 ds/m. The yield reduction can reach 25% at ECw ≥ 1.1 ds/m for strawberry and banana trees, which are widely cultivated in the area.

Table 2: Crop tolerance and yield reduction due to soil and irrigation water salinity.

Crop type	ECe tolerance[1]	ECw tolerance[2]	10% yield reduction at EC_w (ds/m)[3]	25% yield reduction at EC_w (ds/m)[3]
Carrot	1.0	0.7	1.2	NA
Eggplant	1.1	0.7	1.6	NA
Tomato	2.5	1.7	1.9	2.4
Cherry tomato	1.7	NA	NA	NA
Green vegetables	1.0–2.5	1.2–1.3	1.9	2.2
Cucumber	2.5	1.7	2.2	2.9
Onion	1.0	0.8	1.2	NA
Strawberry	1.0	0.7	0.9	1.2
Citrus	1.3–1.5	1.0–1.2	1.6–1.7	2.2
Banana	NA	0.5	0.7[4]	1.1

NA Not available.
[1] FAO reports.
[2] NSW [16].
[3] CFA [17].
[4] Palaniappan and Yerriswamy [18].

These yield reduction estimations presented in the table are alarming in an agricultural area depending mostly on wells in their crop production, especially that most of the cultivated area falls within a 1.5 km strip area along the coast. As we can see in the EC_w results, most the wells, located within this strip area, have their salinity rates exceed the crops tolerance and can, obviously, affect the crops yield.

7 Mitigation and remediation

The deterioration of the aquifers, in this region, is a fact and a quick action is needed for implementing different mitigation and remediation measures to reduce the impacts of the over exploitation of the underground water.

An integrated water management plan should be prepared for this region which is expected to witness more urbanization and population growth (CDR [4]). This plan should include, in the first stage, water allocation study to release the pressure on the underground water through finding more sustainable water resources to bridge the increasing water demand, associated by the demographic growth.

The second stage should go in parallel with the first and focus on aquifer recharge; the study will propose some options, which are implemented word wide and applicable in this area, to fulfil this goal:

1) The region constitute 10 valleys, where rain can be harvested in small dams and used for aquifer recharge, even through natural infiltration or through direct recharge through selected boreholes. Also responsible authorities can investigate the possibility of aquifers' recharge through the karsts caves. So further study is needed for the surficial karstic features to provide necessary information on subsurface routes of the karstic galleries, and follow their behavior in the groundwater flow.
2) The yield from the submarine spring in the studied area is estimated to be 28 mm^3, where most of this water is lost to the sea (Shaaban [7]). This water can be another natural water resource which, if well managed, can fill part of the domestic water demand in the region, or be utilized for aquifer recharge.
3) Recently a wastewater treatment plant was built in Jadra village (see figure 1), and it started to receive wastewater, since summer 2014, from the sewage networks that were installed in part of the studied area and are still under construction in other parts. This treated water can be another choice for aquifer recharge, being a widely implemented option word wide.

8 Conclusion

The demographic growth that is occurring outside any integrated urban plan or any sustainable development measures, in the studied area has its evident impact on the underground water aquifers. The water salinity rates in the wells have exceeded the permissible water standards for domestic and agricultural use. This area, being located on the southern border of greater Beirut area, is expected to witness a continuous demographic growth and consequently increase in the water demand for domestic use. An urgent action plan is needed to, first release the pressure on the underground water by allocating the sufficient quantities of water, from sustainable sources, for domestic use and study the different aquifer recharge options available in this area. Also a thorough research should be conducted to study the impact of the irrigation water salinity on the crops' yield reduction and propose the different management options.

References

[1] Freire M., Urban Planning: Challenges in Developing Countries, International Congress on Human Development, Madrid, 2006. Online. www.reduniversitaria.es/ficheros/Mila%20Freire%28i%29.pdf

[2] World Bank (WB), Urban Development. Online. www.worldbank.org/en/topic/urbandevelopment

[3] Ministry of Environment (MOE), State and Trend of Lebanese Environment Report (SOER), 2010. Online. www.moe.gov.lb

[4] Council of Development and Reconstruction (CDR), National Physical Master Plan of the Lebanese Territory (NPMPLT), 2005. Online. www.cdr.gov.lb/study/sdatl/sdatle.htm

[5] Awad H., Geomorphology, Stratigraphy and Hydrology of the Doha-Damour Area and Hinterland. Master's Thesis, Department of Science, Faculty of Arts and Sciences, American University Of Beirut, Lebanon, 1983.

[6] Arkadan A. R., The Geology, Geomorphology and Hydrology of the Damour-Awali Area Coastal and Hinterland, Master's Thesis, Department of Science, Faculty of Arts and Sciences, American University of Beirut, Lebanon, 1991.

[7] Shaaban A., Etude de L'hydrologie du Liban occidental: utilisation de la télédétection, Thèses de Doctorat. Département de Géologie et Océanographie, L'université Bordeaux I, 2003.

[8] Arab Resource Development (ARD), Integrated Water Resource Management in CAMP area with demonstrations in Damour, Sarafand and Naqura municipalities, Final report. Submitted to the regional activity center for the priority actions program Split, Croatia and Coastal Area Management, Ministry of Environment, Antelias, Lebanon, 2003.

[9] El-Moujabber M., Imad I. & Bou Samra B., Activité Agricoles et qualité des eaux en zone urbaine et périurbaine sur le littoral libanais, Agricultures et ville a l'Est et au sud de la Méditerranée, DELTA-IFPO, Lebanon, pp. 293-311, 2003.

[10] El-Moujabber M., Atallah T., Bou Samra, B., Fayssal S., El Shami D., Mefleh J. & Darwish T, Sea water Intrusion and Crop Response to Salinity in Coastal Lebanon. Lebanese Science Journal, (14)1, pp. 119-128, 2013.

[11] Saad Z., Kapard V., El Samarani A.G., Slim K., Chemical and isotopic composition of rainwater in coastal and highland regions in Lebanon, Journal on Environmental Hydrology, 13 (29), pp. 1-11, 2005.

[12] Massoud M, Assessment of water quality along a recreational section of the Damour River in Lebanon using the water quality index. Environmental Monitoring and Assessment, 184(7), pp. 51-60, 2012.

[13] United States Bureau of Reclamation (USBR), Economic Assessment model, central Arizona salinity study-phase I, Online. www.usbr.gov/lc/phoenix/programs/cass/pdf/Phase1/JTechapdxEconomics.pdf

[14] Darwish T., Atallah T., El Moujaber M. & Khatib N., Salinity evolution and crop response to secondary soil salinity in two agro-climatic zones of Lebanon. Agriculture Water Management, 23, pp. 61-78, 2005.
[15] Paranychianakis N.V. & Chartzoulakis K.S., Irrigation of Mediterranean crops with saline water: from physiology to management practices, Agriculture Ecosystem and Environment, 106, pp. 171-187, 2005.
[16] Department of primary industries (NSW), Salinity tolerance in irrigated crops, prime fact 1345, First edition, 2014, www.dpi.nsw.gov.au
[17] California Fertilizer Association (CFA), Western fertilizer handbook. Horticulture Edition. Sacramento: Prentice-Hall. 279, p. 1990, Online at: www.kno3.org/en/product-features-a-benefits
[18] Palaniappan R. & Yerriswamy R.M., Effect of Saline water irrigation on growth, yield, quality and nutrition of Robusta Banana, Journal of the Indian society of Soil Science, 44(1), pp. 143-146, 1995.