Sustainable Fresh Water Resources Management in Northern Kuwait – A Remote Sensing View From Raudatain Basin

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ABSTRACT

The paper presents time and cost effective remote sensing technology to estimate recharge potential of fresh water shallow aquifers for their sustainable management in arid ecosystem. Precipitation measurement of Raudatain Basin in Kuwait from TRMM data has been made and integrated with geological, geomorphological and hyrological data, to estimate the recharge potential of the basin. The total potential recharge to the area is estimated as 333.964 MCM annually. The initial losses are estimated at 60% of the net precipitation .The net available quantity for recharge is 133.58 MCM.

For sustainable management of the ground water resources, recharge wells have been proposed in the higher order streams to augment the Raudatain aquifer in Kuwait. If the available quantity of precipitation can be successfully utilized, it will reduce considerable pressure on desalination, which is leading to increased salinity off the coast in Arabian Gulf.

KEY WORDS

Raudatain Basin, TRMM Data, Sustainable management of ground water in Kuwait
Recharge of aquifer in arid ecosystem

Introduction

The arid lands in the middle-east have scarcity of water, which affects the human population directly and can be a serious issue of conflict among the neighbors. The freshwater resources are limited mostly to fossil water from the humid past, few shallow aquifers receive recharge through precipitation in the arid ecosystem of the State of Kuwait and adjacent countries, which calls for sustainable management of fresh water resources. Kuwait has two- tier aquifer system comprising Dibdibah Formation of the Kuwait Group at the top and underlying Dammam Formation, which supports the lower aquifer. The Kuwait Group has a shallow aquifer system of Quaternary age, which is unconfined in nature. Lithologically it comprise, silt and gravelly sand. The Dammam Aquifer underlies the Kuwait Group, it is a chalky dolomitic limestone of middle Miocene age, which is under confined conditions, however upward leakages from Dammam Formation are reported at places (Abusada, 1981). The groundwater level varies from 90 m above mean sea level in the southwest to zero at the Arabian Gulf in northeast. The flow follows the regional northeastern dip. The groundwater quality from these aquifers varies from brackish in southwest to highly saline in northeast. The brackish water in the south and central part with TDS less than 3000 ppm is used for irrigation and landscaping, but in the north the water is highly saline with TDS exceeding 130,000 ppm (Burdon and Al Sharhan, 1968, Himida and El-Yaqubi, 1979), which renders it unfit for direct use.

Only few shallow aquifers have renewable groundwater potential in the middle-east, Raudatain Basin in Kuwait is one of them. The shallow aquifers are irreparably damaged by over exploitation in the arid lands; the authors present time and cost effective remote sensing technology to estimate recharge potential of fresh water shallow aquifers for their sustainable management in arid ecosystem.

Study Area

The fresh water in northern Kuwait occurs as lens in Raudatain area. This lens floats over the highly saline groundwater in the northern part of the country. The Raudatain fresh water lens is used for bottling drinking water. The recharge to the fresh water lens has not been estimated, this study is envisaged to provide an insight into use of remote sensing technology to estimate recharge potential to the Raudatain fresh water lens for sustainable development.

The study area lies to the north of Kuwait city (Fig. 1). Geologically the area is upper Miocene – Lower Pleistocene age and belongs to upper Dibdibah Formation of Kuwait Group (Fig.2). Lithologically the formation consists of coarse grain pebbly sand with thin intercalations of clayey sand and clay, pebbles, cobles, gravel and conglomerate. The assemblage is similar to a fan deposit. The surface geology shows consolidated calcritic deposit, which is helpful in combating aeolian and fluvial erosion to a large extent, but impedes recharge to the shallow aquifers.

The Dammam Formation underlies the Kuwait Group. It is Middle Miocene in age, lithologically comprising of inter-bedded marine marls, limestone and clays. The thickness of this formation varies from 30 m to 101 m. The limestone horizons are karstified in the Dammam Formation. The yield from the karstified limestone horizons of the Dammam Formation estimated in adjacent Al Hasa area in eastern Saudi Arabia vary between 12 – 14 m^3/sec (Edgell, 1997). The area experience high evaporation @ 16.6 mm/day (Kwarteng and Al Ajmi,1997) , manifested by secondary salinity along the drainage channels (Fig. 3) and low infiltration of bedrocks (20 cm/h) (Al Sulaimi et al., 1997) as is evident from seasonal playas that are formed after a rain event.

The entire State of Kuwait is dissected by a network of channels, most of which are confined to the Dibdibah Formation of Kuwait Group, of Upper Miocene – Lower Pleistocene age (Al Sulaimi et al., 1997). The drainage mapping of northern Kuwait is attempted to demarcate the catchment boundary of the Raudatain basin using Landsat ETM data (Fig.4). The Raudataion Basin shows centripetal drainage with low gradient.

Methodology

The present communication is intended to estimate the potential recharge to the Raudatain fresh water lens, essential for environmentally compatible and ecologically sustainable development of the water resources in northern Kuwait. The recharge potential of the basin has been estimated in the present study by integration of the precipitation data with the geology, geomorphology and hydrological parameters.

The present study utilized Landsat ETM and Radarsat data for identification of the present and paleo channels. The digital elevation model was created using Shuttle Radar Topography Mission (SRTM) data. The geology of the area was taken from published maps and literature.

The PCI Geomatica software has been used for image registration, processing and interpretation. The Landsat ETM image was registered with the topographical sheets of Kuwait produced by Directorate of Surveying, Army General Staff Headquarter, Ministry of Defence, Kuwait. The registration processes involved collection of 30 GCP comprising of pseudo invariant features (PIF's) (Schott et al., 1988) from all over the scene. The registered scene was projected in UTM 38R WGS 1984 projection. The Radarsat data of March 1997 was co-registered with the Landsat Image and projected to UTM 38R by image to image registration. The SRTM data was also co-registered with the Landsat Image to extract the corresponding elevation information. The resolution of the SRTM data is 90 meters, this corresponds to 9 pixels in Landsat image, which will show same elevation. This limitation will be solved after ASTER data is used for creation of DEM (there is ongoing project to create DEM from ASTER Level 1A data over Kuwait which will be utilized at the operationalisation stage of the R&D presented in this study).

The precipitation was estimated through interpretation of Tropical Rainfall Measuring Mission (TRMM) data, which provides accurate spatial and temporal variation of global rainfall, intensity, distribution and latent heat. It is capable of detecting rains as little as 0.7mm/hour. We lack ground truth for the precipitation over the study area on continuous basis; the TRMM data which is available 3 hourly helped to over come this limitation. We have selected the scenes where rainfall events are shown over the study area in year 2003.

The resolution of the TRMM data is 4km, which is coarse but still gives a couple of values over the basin , thus we prefer to use it instead of a point observation. The data was coregistered with the Landsat image. Fig. 5 shows 29 days on which precipitation took place in 2003 and the total precipitation is estimated from TRMM as 116 mm from 1st January, 2003 to 31st December, 2003. Fig. 6 shows the mean daily precipitation during each month.

The extraction of geological and geomorphological information from Landsat data was attempted. These layers are integrated with the Digital Terrain Elevation Model (DTEM) extracted from SRTM to delineate the basin margin. The geological and geomorphological factors which control the runoff and recharge through precipitation are dependent on porosity, permeability of rocks and the recharge potential, which are controlled by lithology and structure. The runoff and recharge of groundwater is dependent on landforms, drainage and relief characteristics (Saif ud din and Al Rumikhani, 2004).

The relief data for the study area was calculated from SRTM (Fig. 7). The relief setting of the watershed is an indicator of runoff/recharge potential. The possibility of recharge within an area of irregular relief pattern is poor; the low lying areas have a better chance of the recharge. For this reason the drainage channels and relief pattern in the watershed are studied.

The actual estimation of recharge is a complex process which takes into account the initial losses and runoff in the basin (Gheith and Sultan, 2002). The Natural Resources Conservation Service (NRCS) method of the United States Department of Agriculture (SCS, 1985) was used to calculate the initial losses in the sub basin. The transmission losses in the basin were computed using the expression developed by Walters (1990) for similar climatic conditions in Saudi Arabia. The precipitation values are taken as cumulative monthly values calculated from TRMM data.

The initial step in estimation of recharge in this micro-watershed is development of digital terrain elevation model (DTEM). The DTEM is generated using the SRTM data. The drainage channels picked up from Landsat and Radarsat data were integrated with the DTEM data.

The PCI focus was used to vectorize the drainage channels. The microwater shed is demarcated from these drainage lines and elevation information. The area of the micro watershed is calculated, besides other morphometric parameters.

Databases

To have a synoptic view and to integrate the thematic information required for recharge estimation in the micro watershed the thematic files on topography, geology, geomorphology and precipitation were generated.

The Landsat scene of path row 165-039 of March 2003 was taken since the tonal contrast was good between the drainage channels, bare sand, lithology due to higher moisture saturation. The cloud coverage was less than 5%.

Geologically the Raudatain Basin comprise sediments of Dibdibah Formation of Kuwait Group, lithologicallly it represents fan deposit. Geomorphologically the area is situated at fringe of the two main physiographic regions, the sedimentary sequence of the Arabian monocline to the south and southwest and Mesopotamian plain with Shatt Al Arab delta to the north and northwest. The surface topography is monotonously flat to gently rolling desert plain having a shallow inland depression.

The Raudatain basin is elongated in northeast-southwest. The watershed is delineated by using SRTM data from 3 arc second DTEM. The relief information was exported into DEM format using PCI. The Raudatain Basin measures 2879 km^2 in area which is sub divided into 16 sub basins (Fig. 8).

The basin is showing a centripetal drainage with channels draining from southwest and east into a depression in eastern part of the basin. In the present study we have considered all the cells draining into the same outlet as part of one micro watershed. With this logic we are able to delineate sixteen micro watersheds within the Raudatain basin. The morphmetric parameters have been calculated. The results are given in Table 1.

Hydrogeology

The precipitation data calculated from TRMM over the basin were used to estimate the recharge potential of the basin. The actual recharge to the underlying aquifer is considerably less, since it equals to the precipitation minus initial and transmission losses.

The initial losses occur in the basin before the runoff reaches the drainage network, while there are transmission losses during the channeling of the water through the drainage channels. The initial losses are largely related to the infiltration, surface soil type, landuse/ landcover, evaporation and evapotranspiration and interception. The MCRS method is used to estimate the initial losses which suggest that runoff in the basin will occur after rainfall exceeds an initial abstraction (I_a) value. Rainfall excess, Q in the NRCS method is related to the effective precipitation (P - I_a), through a maximum potential retention value, S. Thus Q can be expressed by equation (1), where all the measurements are in inches:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (1)$$

The maximum potential retention S is a function of an empirical curve number (CN) and is expressed as equation (2) :

$$S = \left(\frac{1000}{CN} - 10 \right) \qquad (2)$$

The initial abstraction as suggested by NCRS for similar conditions is 20% of maximum potential retention. Thus $I_a = 0.2S$.

The CN is a function of antecedent moisture condition (AMC), the landuse, the hydrologic condition and soil type. In the study area the antecedent moisture condition is believed to be low, since the rain events are rare and usually months apart. The landuse and hydrologic conditions were classed as Natural Desert landscaping and desert shrub coverage less than 25% of ground. In the watershed there are 5 soil types (Table – 2) namely the haplocalcids, torripsamments, calcigypsids, petrogypsids and miscellaneous (unclassified soil) (Fig. 9).

The infiltration rates in Raudatain basin vary between 4 cm/h to 67 cm/h (Al Sulaimi et al, 1997). The low infiltration of 4 cm/h was reported in the playas in the north of the basin. Where as on the upper Dibdibah Formation shows an infiltration of 15 cm/h, while gravely desert flood deposits show infiltration rate of 35 cm/h. The wadi fill shows a high infiltration of 67 cm/h.

Result and Discussion

The remote sensing technology has provided a very detailed view about the hydrodynamic situation of the Raudatain Basin. These observations can be very useful inputs in the quantitative hydrologic modeling. The use of Landsat data to extract thematic information about the geology and geomorphology and integration of elevation information derived from SRTM data proved to be very useful in basin demarcation and to anticipate runoff-recharge flows.

The TRMM data provided the basic information about the precipitation in the basin with high spatial, temporal and thematic accuracy. The use of TRMM data gave us enough control points over the basin to precisely estimate the annual precipitation.

The paleo and present drainage system in Kuwait are potential sites for fresh water recharges. The high infiltration rates of wadi fill deposits are helpful in facilitating recharge to shallow aquifers within the Raudatain basin.

It is proposed that recharge wells may be constructed on the highest order channel in each micro watershed, this will facilitate quick sub surface recharge leading to reduction in runoff and evaporation losses.

The concept seems sound as certain point locations within the Kuwait group aquifer system shows correlation between salinity distribution and channel ordering, i.e. low salinity had been observed in higher order channels in down stream direction, which suggest that fresh recharge has taken place in the area. The suggested concept of constructing recharge wells on higher order channels will facilitate further recharge and will reduce evaporation losses, which take place due to formation of playas on surface.

The total potential recharge to the area is estimated as 333.964 MCM annually. The initial losses are estimated at 60% of the net precipitation thus the net available quantity for recharge is 133.58 MCM. We believe that if half of this quantity can be successfully utilized, it will reduce considerable pressure on desalination, which is leading to increased salinity off the coast in Arabian Gulf.

The 133 MCM /annum of fresh water can make Raudatain basin as a sustainable source of fresh water for a better part of the country. This study shows a light of hope that sustainable water resource development can be a possibility in desert state of Kuwait. The theoretical estimates, based on remote sensing TRMM data have a confidence level of 50 – 60% actual recharge quantity may be less than the predicted value. However true quantitative estimate of runoff – recharge should be taken by future researchers by integrating remotely sensed data with ground truth.

Acknowledgements

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Figures and Captions

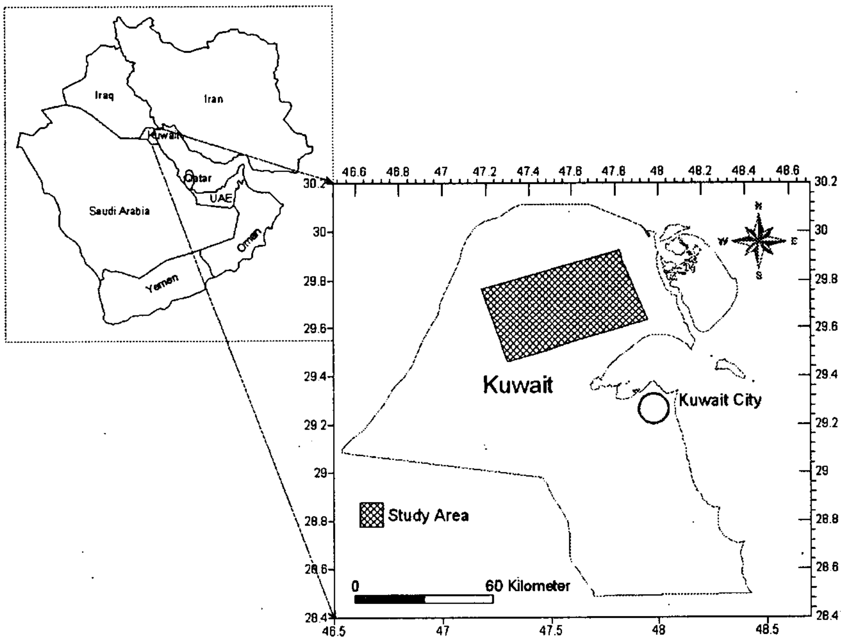


Fig. 1. Location Map of the Study area

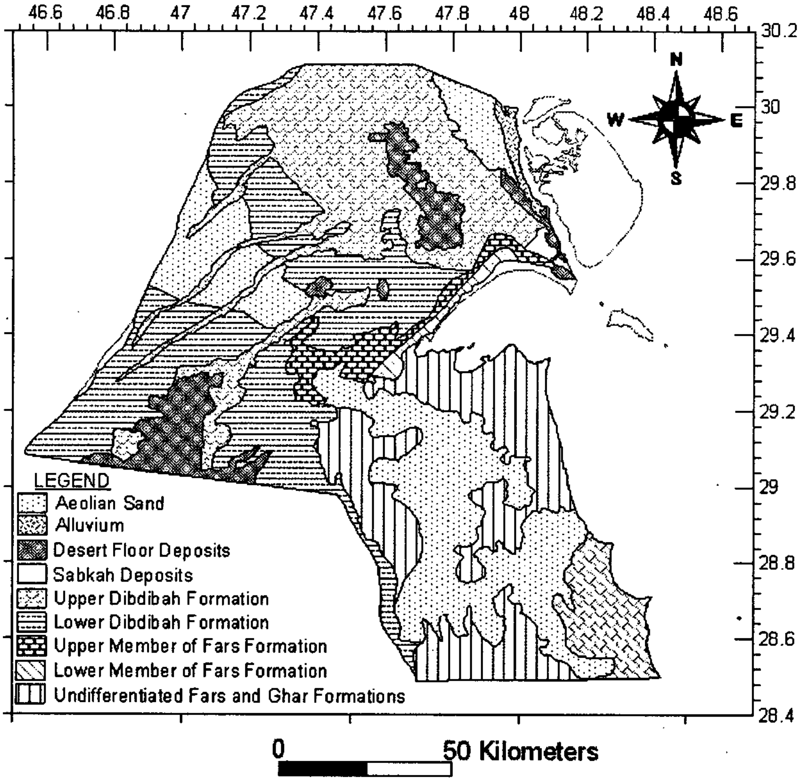


Fig. 2 Simplified Geological Map of Kuwait (after Anon, 1981)

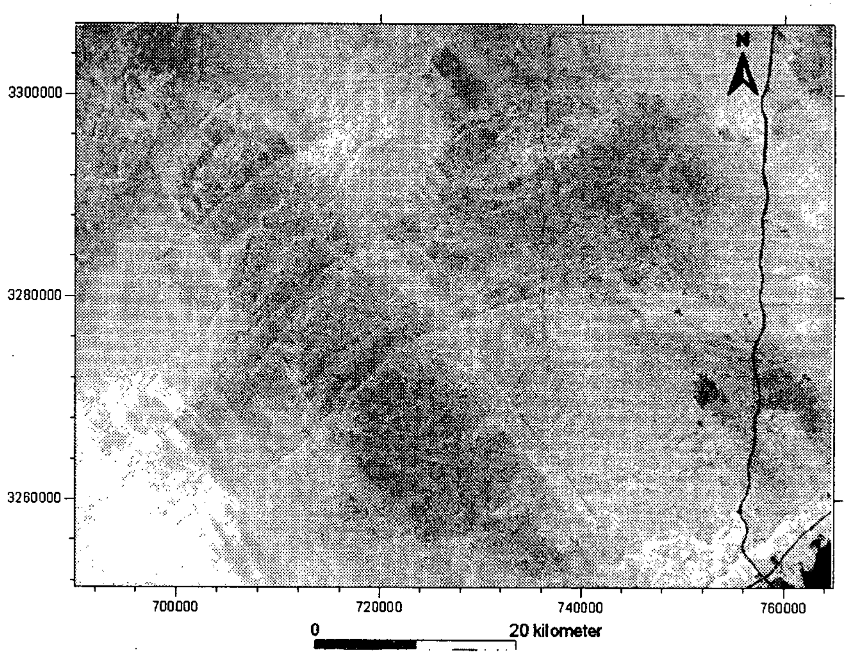


Fig. 3. Landsat Image showing secondary salinity along the palaeo channels. Note bluish hue and higher brightness due to salt encrustation.

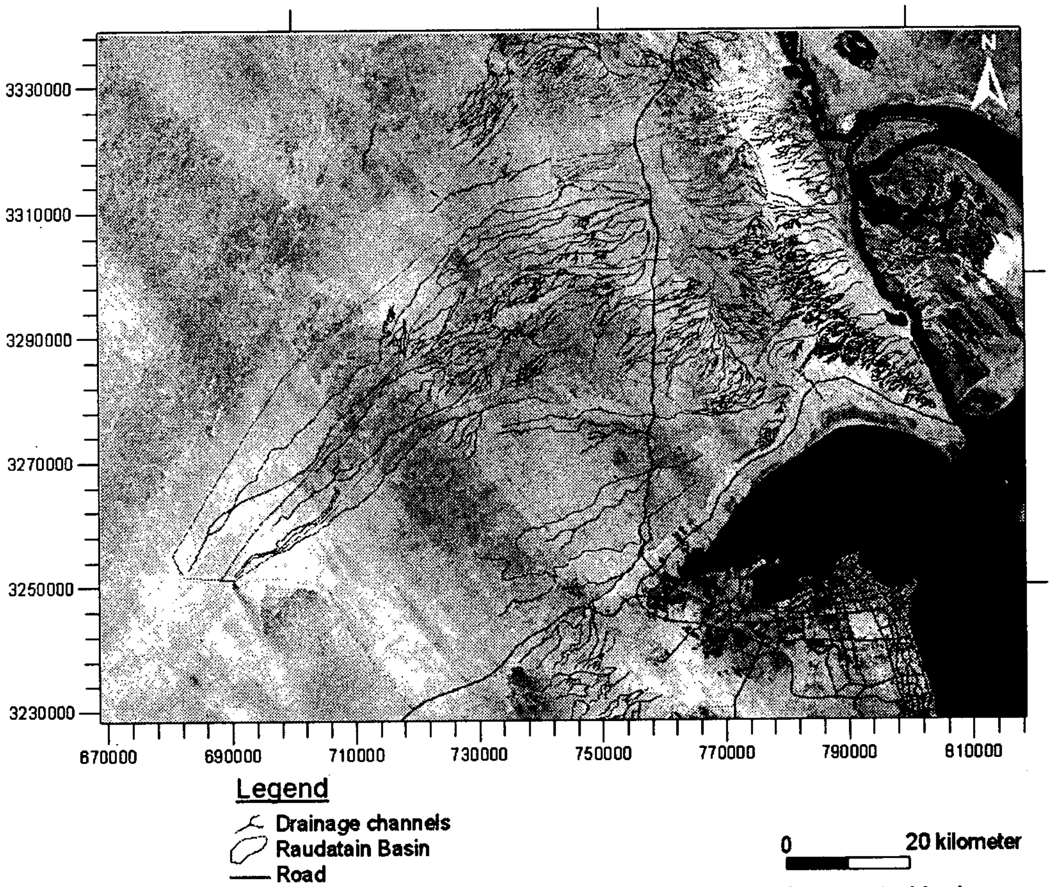


Fig. 4. Landsat ETM Image showing the Raudatain drainage basin demarcated by brown polygon

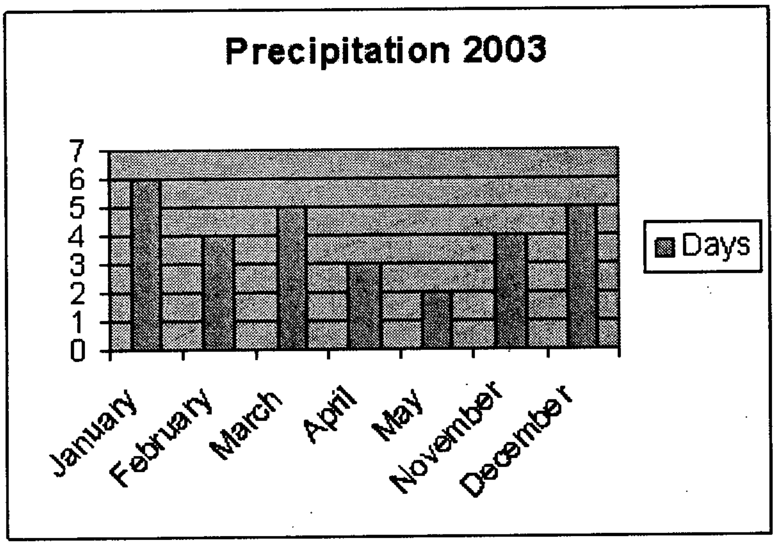
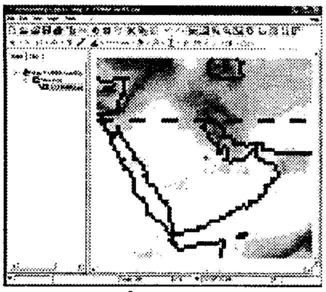


Fig. 5 Total Number of rainy days in each month



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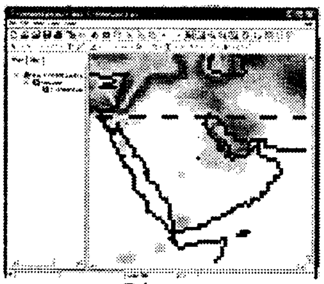

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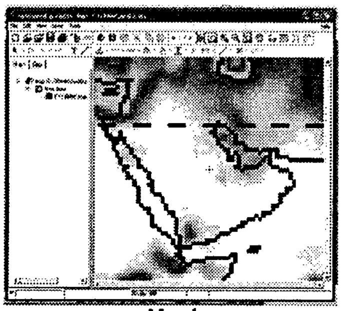

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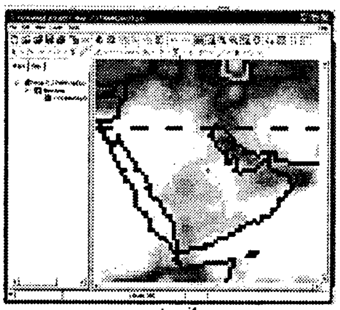

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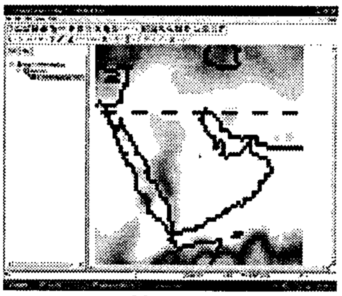

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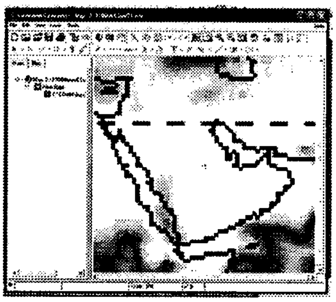

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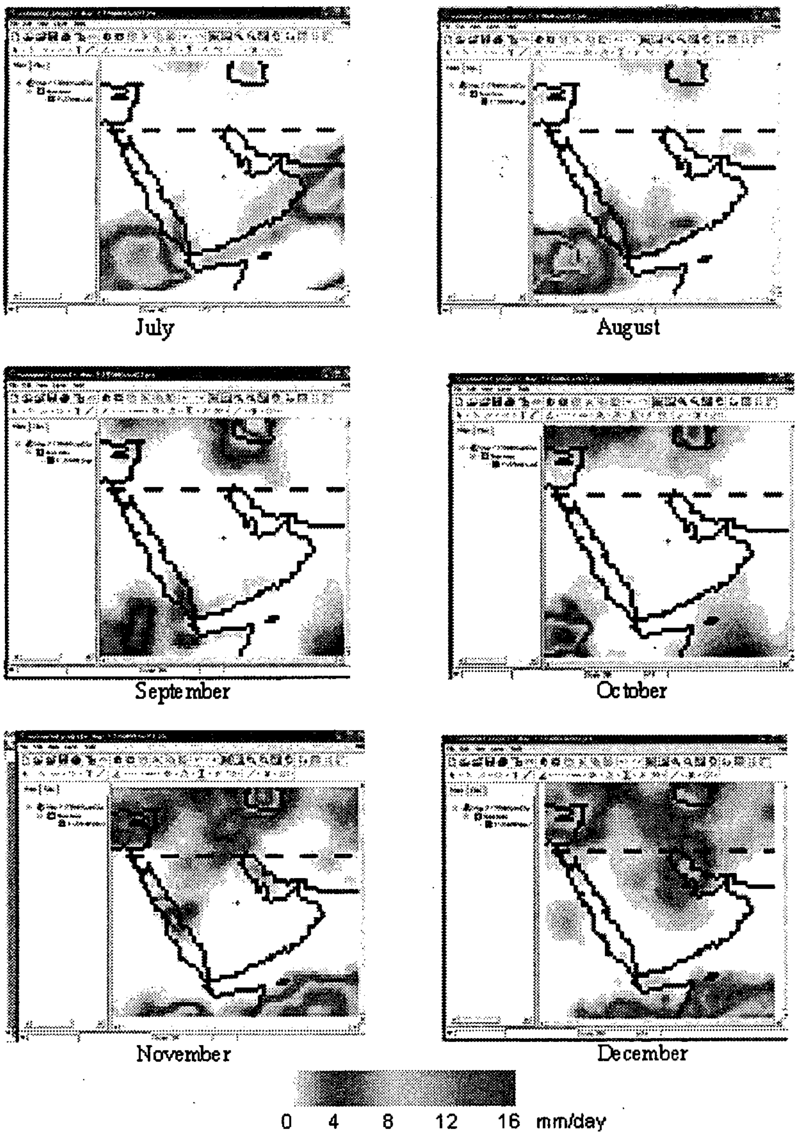

Fig. 6 Mean monthly precipitation in millimeters/day

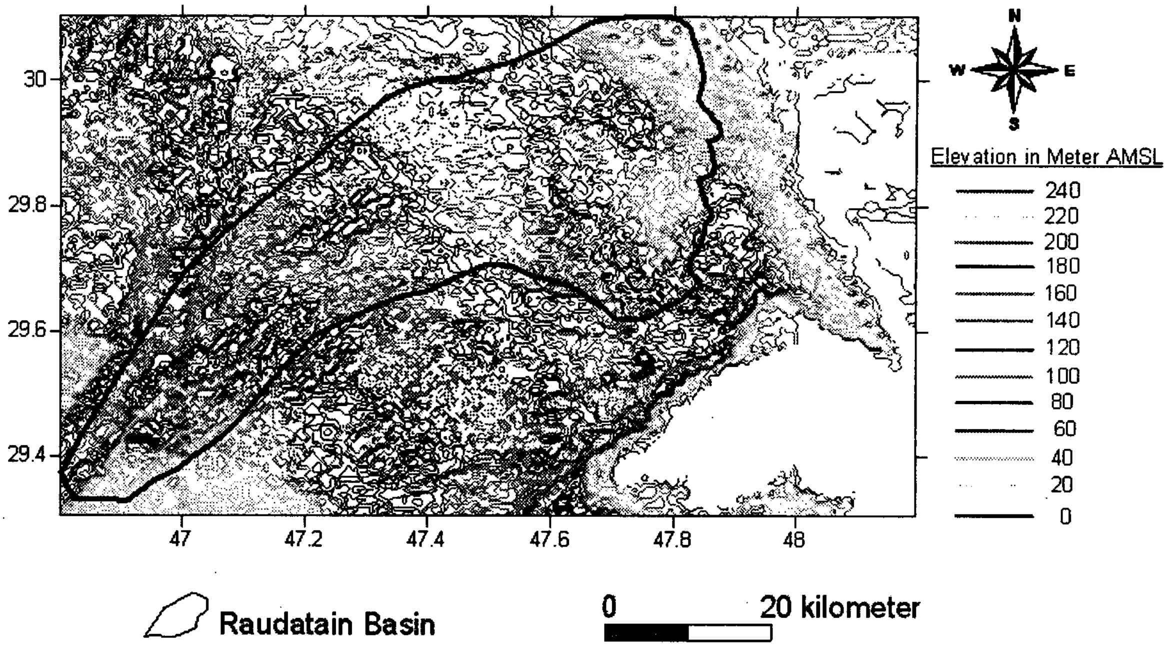

Fig. 7. Relief of the Study area (Raudatain basin marked as black polygon)

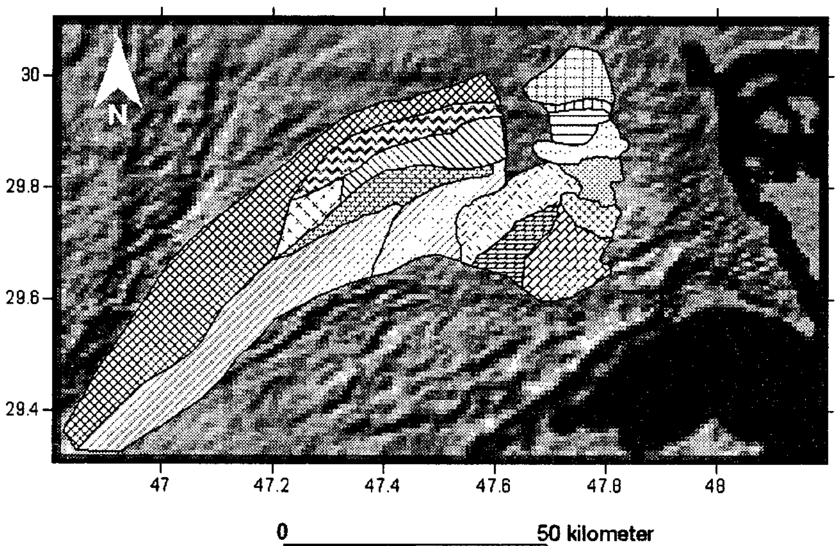

Fig.8. The micro watersheds within the Raudatain basin.

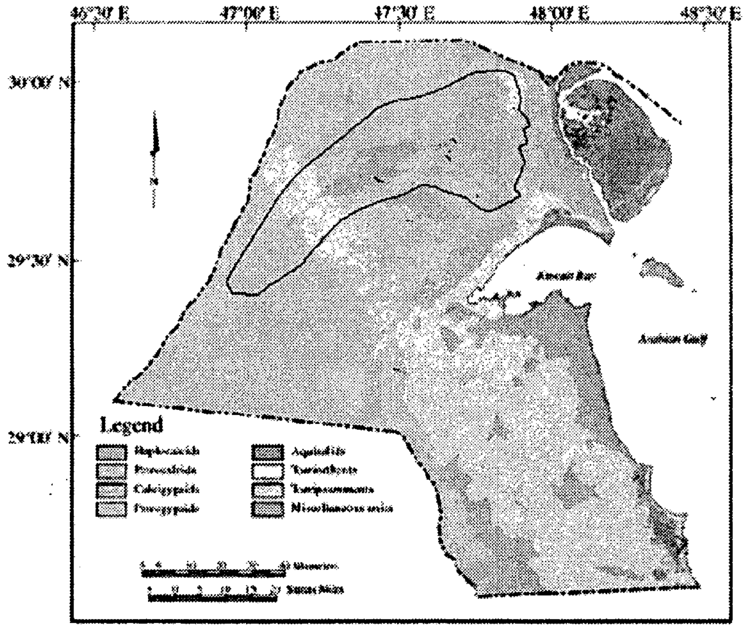

Fig. 9. Soil Map of Kuwait (after Omar et al.,2001)