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GROUNDWATER STUDIES IN ARID AREAS IN EGYPT USING LANDSAT SATELLITE IMAGES

E. M. EL SHAZLY, M. A. ABDEL HADY, & M. M. EL SHAZLY

REMOTE SENSING CENTER, ATOMIC ENERGY ESTABLISHMENT AND DESERT INSTITUTE, CAIRO, EGYPT

SUMMARY

About ninety seven percent of the land of Egypt is covered by deserts lying in one of the major arid zones of the world. These deserts include the Western Desert, the Eastern Desert and the Peninsula of Sinai. Groundwater represents an important problem to be tackled for the development of these deserts and their utilization.

The interpretation of LANDSAT satellite images for large areas in the deserts of Egypt has been going on for more than four years, and its comparison with the pertinent information on groundwater aquifers in these areas deciphered a considerable number of questions regarding the conditions, source and potential of the groundwater.

Various features are interpreted which have strong bearing on groundwater in the arid environment. These include the nature of geological and lithologic units, structural lineaments, present and old drainage systems, distribution and form of water pools, geomorphologic units, weathering surfaces and other weathering phenomena, desert soils, sand dunes and dune sand accumulations, growths of natural vegetation and agriculture, and salt crusts and other expressions of salinization. The same features could be utilized in the regional exploration and management of groundwater aquifers in the arid zones.

There are many impressive examples which illustrate the significance of satellite image interpretation on the regional conditions of groundwater which could be traced and interconnected over several tens or even several hundreds of kilometers. This is expecially true in the northern Western Desert of Egypt where groundwater issuing from deep strata comes to the surface along ENE-WSW and ESE-WNW fault lines and fracture systems. Fresh to brackish and saline springs, and water pools in the depressions of this part of the Western Desert owe their origin to this striking phenomenon. These include Siwa Oasis Depression, Qattara Depression and El Bahrein Depression. In fact, the livelihood of the population of Siwa Oasis depends on such springs and pools.

Another striking example is illustrated by the occurrence of fresh to brackish groundwater on the Mediterranean Sea Coastal Zone of the Western Desert where the groundwater is found in the form of lenses floating on the saline sea water. This phenomenon is caused by the presence of certain highly porous and permeable detrital limestones which belong to a geological unit, extending along the coast, called Alexandria Formation. This latter unit has been delineated along a distance on the coast of some five hundred kilometers, accurately and in a short time by the interpretation of LANDSAT satellite imagery.

INTRODUCTION

The territories of Egypt cover one million square kilometers (Figure 1), of which some 700,000 square kilometers have been mapped by the Remote Sensing Center in Cairo through the application of LANDSAT imagery. The maps are normally produced on a scale of 1:500,000 and they are usually reduced for the sake of publication to the handy scale of 1:1,000,000.

The prevailing very arid to arid conditions over the country necessitate the dominance of desert conditions in general with the exception of the Nile Valley where the fertile lands are irrigated by the water of the River Nile. Dispersed cultivations are noted in the peripheries of the Nile Valley, in the Mediterranean Sea Coastal Zone where annual rainfall may range between 150 and 200 mm and the groundwater is accessible, and in some oases and valleys where groundwater is stored in aquifers under conditions favorable for exploitation. The cultivated lands of the Nile Valley represent 3% of the coverage of Egypt, while the remaining 97% of the lands are deserts where dispersed cultivations may be present under special conditions.

LANDSAT imagery are available as computer compatible magnetic tapes and as printed images which are made on positive transparencies or opaque prints for each of the four bands of the multispectral scanner mounted on LANDSAT satellites. These are bands 4, 5, 6, and 7 corresponding to the green, red and two near infrared spectral ranges respectively, of which bands 5 and 7 have been found most suitable for mapping in the prevailing natural conditions of Egypt especially in positive transparencies. Mixing and ratioing of combinations of three of the four bands produce false color composite images, which are utilized for mapping especially, in their positive transparencies, in addition to the previously mentioned images of bands 5 and 7. The computer compatible tapes mounted on Bendix M-DAS system provide enlarged and digitized LANDSAT imagery and facilitate mapping of the natural units and phenomena in great diversification and considerable detail. Intensive field verification, and frequent reciprocal exchange of practical experience between the office interpretation and field verification of the mapped natural units are necessary for the production of high quality maps. In spite of all the steps through which map production by LANDSAT imagery interpretation has to proceed, yet the time consumed in such proceedings is much less than that consumed through the application of previous techniques. Meanwhile, the synoptic and repetitive coverage of the natural units and phenomena in their various diversifications and manifestations represent particularly important advantages of the utilization of LANDSAT imagery in regional mapping.

The experience gained, during a period exceeding four years, in the application of LANDSAT satellite imagery interpretation in elucidating the groundwater conditions and related phenomena in Egypt is remarkable, especially when combined with the other hydrogeological and hydrological studies carried out on the pertinent water bodies exposed on the surface or hidden in the subsurface. Few examples are given in this communication concerned with the application of LANDSAT-1 imagery technique in studying regional groundwater conditions and manifestations in selected areas in Egypt.

WESTERN PERIPHERIES OF THE NILE DELTA

The distribution of groundwater in the Nile Delta is closely linked with the development of the geological history of the Delta from the Miocene times to the present, and with the influence of infiltration of the Nile water in the subsurface, Mediterranean Sea water intrusion and percolation of the rain water into the sedimentary cover of the concerned area.

The history of the Nile Delta since the Miocene as expressed in the delineation of the sediments covering the Nile Delta environs which range in age from Miocene to Holocene and the structural lineaments which bound the Nile Delta graben in its consecutive stages of development during the same time period has been elucidated through the application of LANDSAT imagery mapping techniques (El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975).

The various aquifers dominating the Nile Delta and its western peripheries have been delineated on a regional scale by utilizing LANDSAT imagery interpretation in combination with the hydrogeological and hydrological data on the aquifers in question. The latter include leaky water in Holocene deltaic sands, free water in Holocene dune sand accumulations and Pleistocene detrital limestone, sub-artesian water in early Pleistocene sand and gravel, unconfined water in early Pleistocene sand and gravel, semi-confined water in early Pleistocene sand and gravel (resulting from irrigation by Nile water passing through canals), and unconfined to semiconfined water in Neogene sandy facies (Figure 2). It may be noted in the same figure that the boundaries of the aquifers on the western peripheries of the Delta attain roughly a NW-SE trend which is almost the same direction as the main faults limiting the Nile Delta westwards during its tectonic development from the Miocene to the Holocene.

Apart from delineating the water-bearing geological units in the discussed area, LANDSAT-1 imagery interpretation has led to the mapping of units related to the salinization of water in the Nile Delta environments including salt crust and salty surficial materials, and marshes and sabkhas. All these expressions of conditions and manifestations of water are important in its exploration, exploitation and management in the Nile Delta and its environs where the greatest proportion of the population of Egypt are living.

SIWA OASIS AREA, WESTERN DESERT

It has been demonstrated by LANDSAT mapping techniques that the depressions in the northern Western Desert are greatly controlled by long faults and fractures of about E-W trend which extend for tens to hundreds of kilometers (El Shazly, Abdel Hady, El Ghawaby, Khawasik and El Shazly, 1976; etc.). In the meantime water ponds, springs and water wells distributed in the same area have been found to be spatially related in most cases to the above mentioned linear elements.

Figure 3 of Siwa Oasis located in the western part of the northern Western Desert illustrates very clearly the relation of the distribution of the water ponds to the delineated faults and fractures assuming an ESE-WNW trend and their intersections with those acquiring a NW-SE direction. Actually, one of the major ESE-WNW faults extends for a very long distance from the Siwa Oasis Depression westwards to the southern part of the Qattara Depression eastwards. In a comparable fashion the small depressions and water ponds extending from El Bahrein to Sitra are localized on the ENE-WSW faults and fractures.

Groundwater in Siwa Oasis is the only source of water supply available for domestic and irrigation purposes. The ESE-WNW faults delineated on the pertinent LANDSAT images by traversing the suitable water-bearing horizons, namely the Miocene, Eocene and Late Cretaceous-Early Carboniferous sediments, bring the groundwater to the ground surface or near it. In this way the groundwater is made accessible for consumption, either discharged by natural springs or man-dug wells of relatively shallow depths. The water ponds noted along the fault lines in Siwa Oasis Depression represent the water accumulating by groundwater discharge which is subjected in the mean time to evaporation and salt concentration.

Comparative features to those found in Siwa Oasis are noted in Kharga and Dakhla Oases Depressions where the faults and other lineaments mapped by LANDSAT imagery techniques have been found to control to a considerable extent the alignment of water ponds in this area located in the south Western Desert (El Shazly, Abdel Hady, El Kassas, Salman, El Amin, El Shazly and Abdel Megid, 1976).

MEDITERRANEAN SEA COASTAL ZONE

To the west of Alexandria and extending to the Egyptian-Libyan borders the Mediterranean Sea Coastal Zone is dominated by an important water-bearing geological unit of Pleistocene age termed Alexandria Formation. This unit has been delineated and mapped regionally along the whole Coastal Zone through the application of LANDSAT imagery interpretation techniques (El Shazly, Abdel Hady, El Ghawaby, El Kassas, Khawasik, El Shazly and Sanad, 1975).

Alexandria Formation has been differentiated into members constituted of detrital limestones (Figure 5), with or without indurated crusts, associated with clayey calcareous soils and a clay-gypsum member. The former members are essentially constituted of limestones of high permeability which possess cavities of various dimensions caused by karstification and other dissolution phenomena. These limestones represent an important aquifer in the Coastal Zone where the rain water is stored as large lenses floating on the intruding saline water of the Mediterranean Sea. The gentle topography combined with the relative softness of the limestones allow the roots of the cultivated plants to reach the water table attained by the fresh-brackish water lenses. Accordingly, the dispersed cultivation of the Coastal Zone is greatly dependent on the distribution of the outcrops of the mentioned limestones.

The capability of the detrital limestones to store water in their pores and cavities is enhanced by the configuration of the drainage lines which act as channels for runoff water. These either drain their water in closed lows or towards the Mediterranean Sea. The drainage map of a part of the Coastal Zone in the neighbourhood of El Alamein (Figure 4) shows the drainage pattern as delineated from LANDSAT images.

Furthermore, the clay-gypsum member of Alexandria Formation plays an important role in water logging and salinization in the Coastal Zone due to its impermeability and salt content. This unit has been delineated as islands outcropping in various parts of the Coastal Zone to the south of the detrital limestone exposures where they make the basal part of Alexandria Formation. It may be concluded from the above mentioned discussions that the mapping of the aquifers and aquicludes, as well as the drainage systems in the Mediterranean Sea Coastal Zone by LANDSAT imagery interpretation has given an overall regional picture of its groundwater potential.

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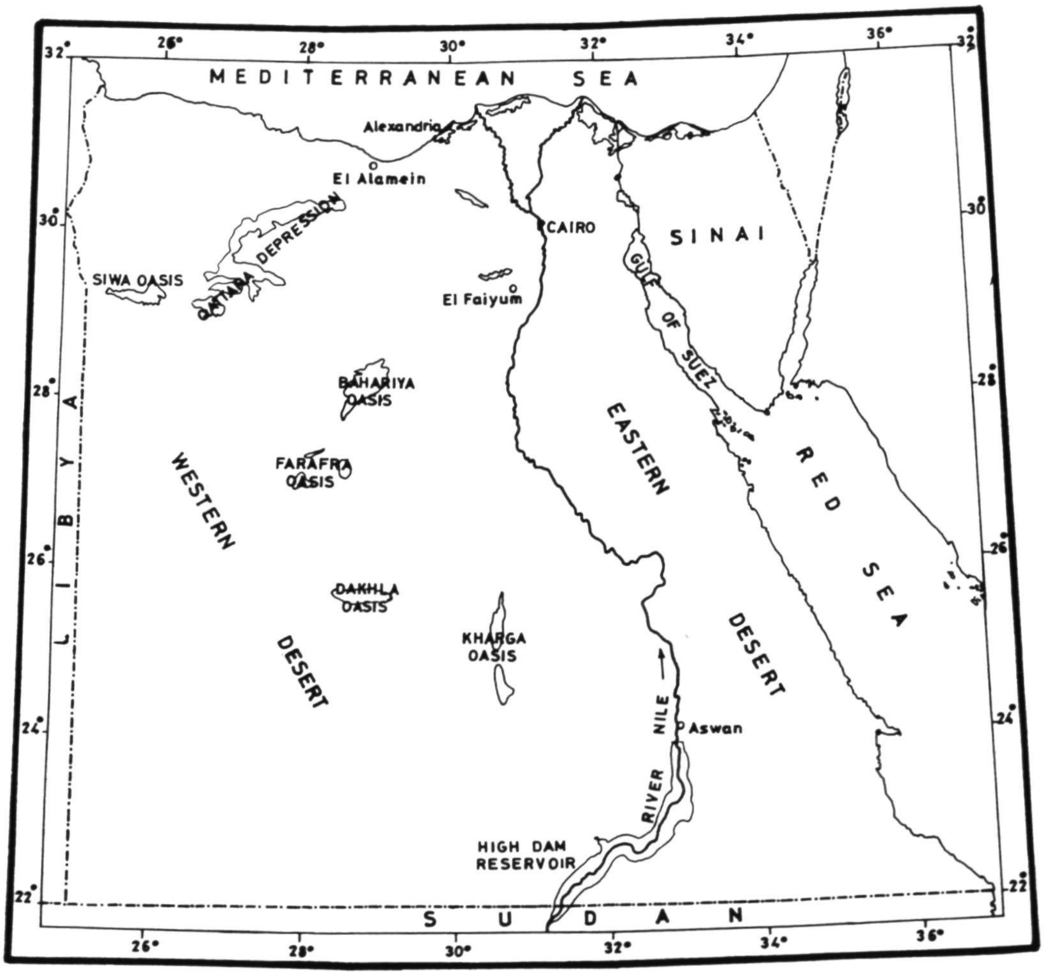

FIGURE 1. MAP OF EGYPT SHOWING CITED LOCALITIES.

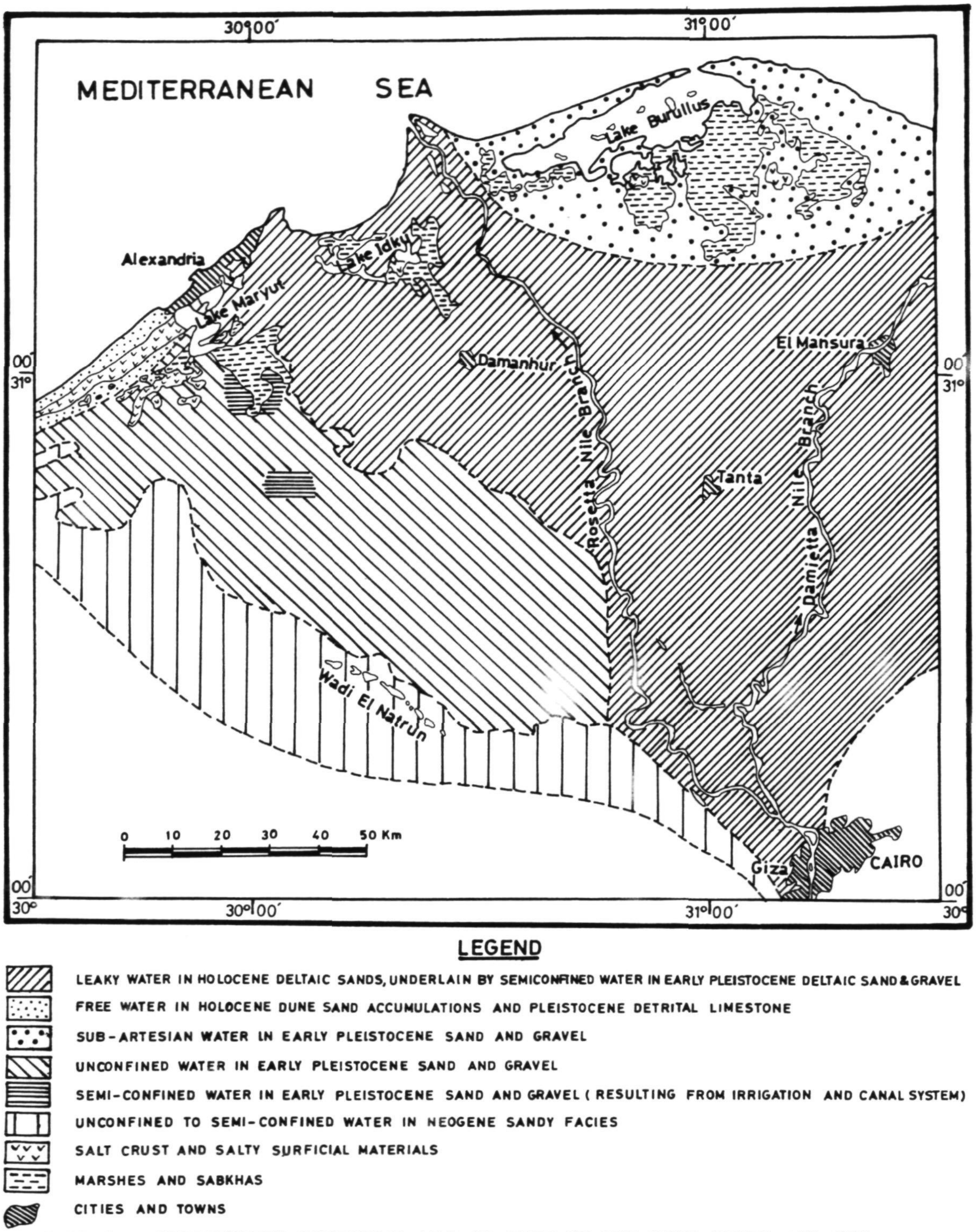

FIGURE 2. GROUNDWATER POTENTIAL MAP OF PART OF THE NILE DELTA AND ITS WESTERN PERIPHERIES.

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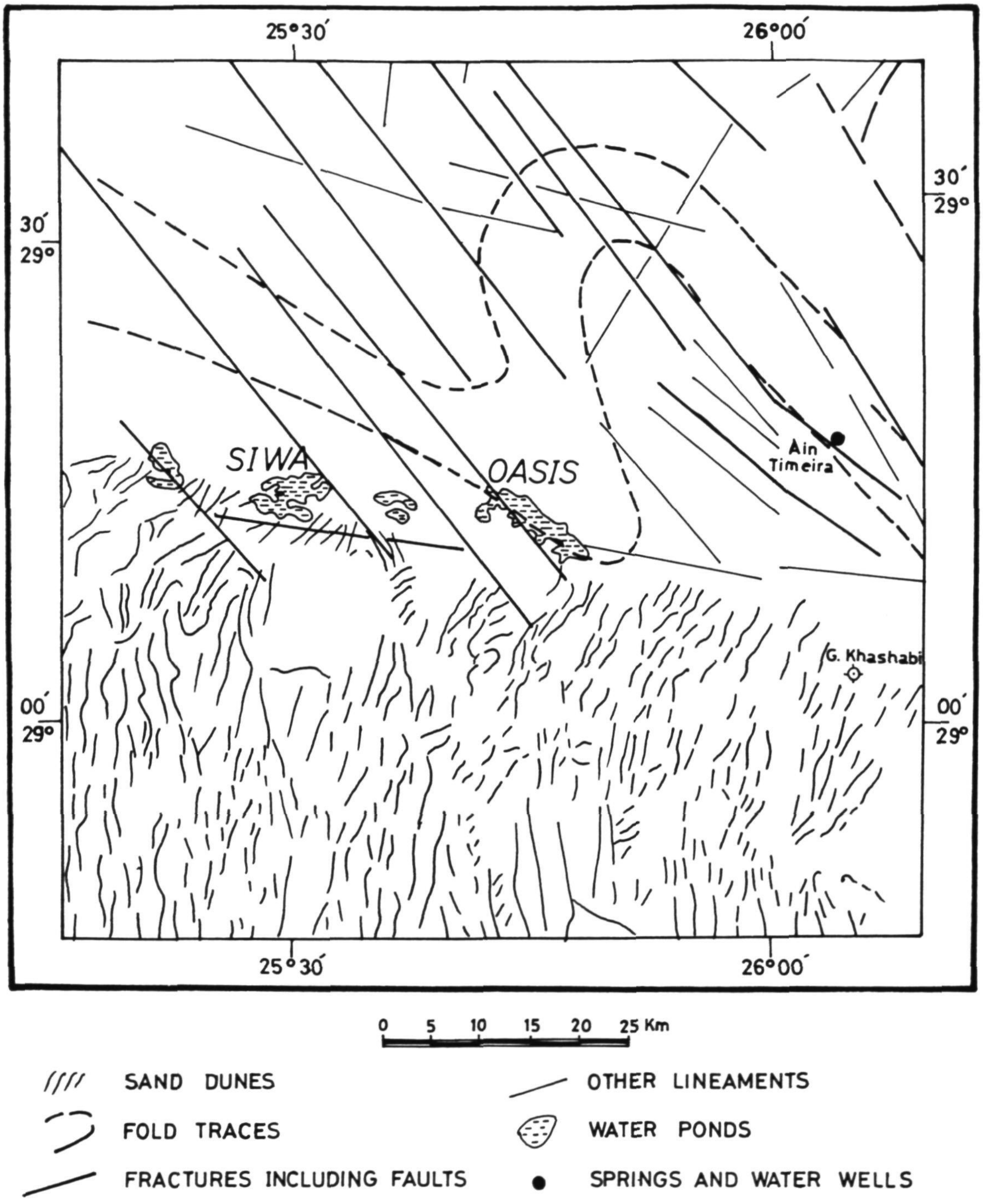

FIGURE 3. MAP OF SIWA OASIS ENVIRONS ILLUSTRATING RELATION OF STRUCTURAL LINEAMENTS TO WATER PONDS.

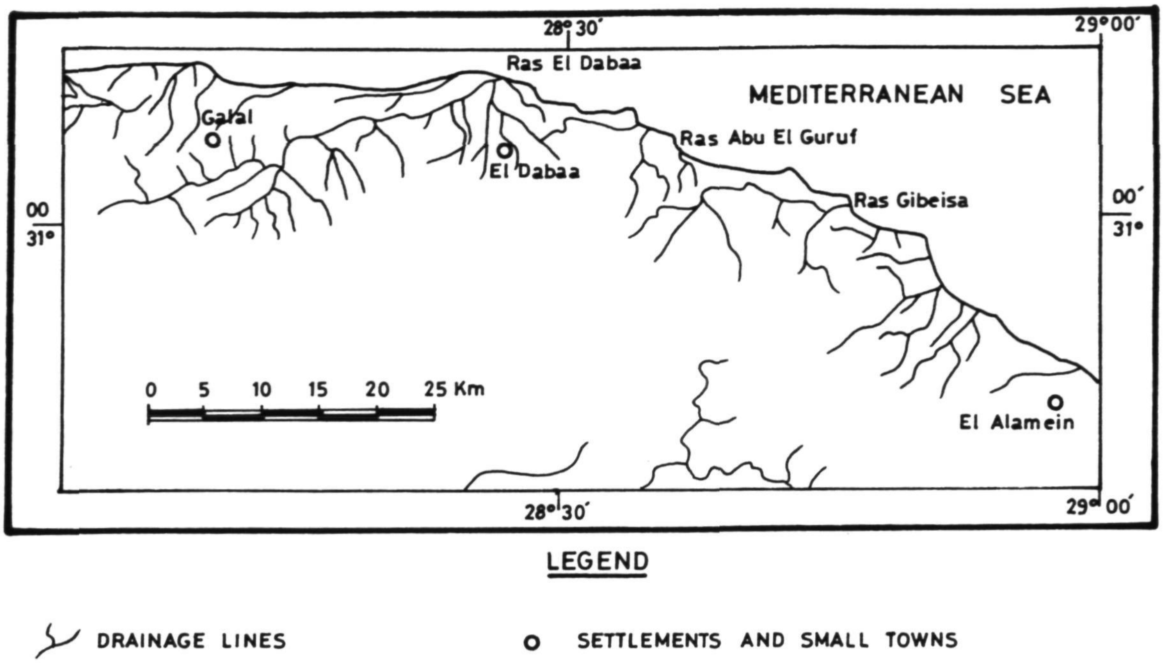

FIGURE 4. DRAINAGE LINES IN THE MEDITERRANEAN SEA LITTORAL AT EL ALAMEIN NEIGHBOURHOOD.

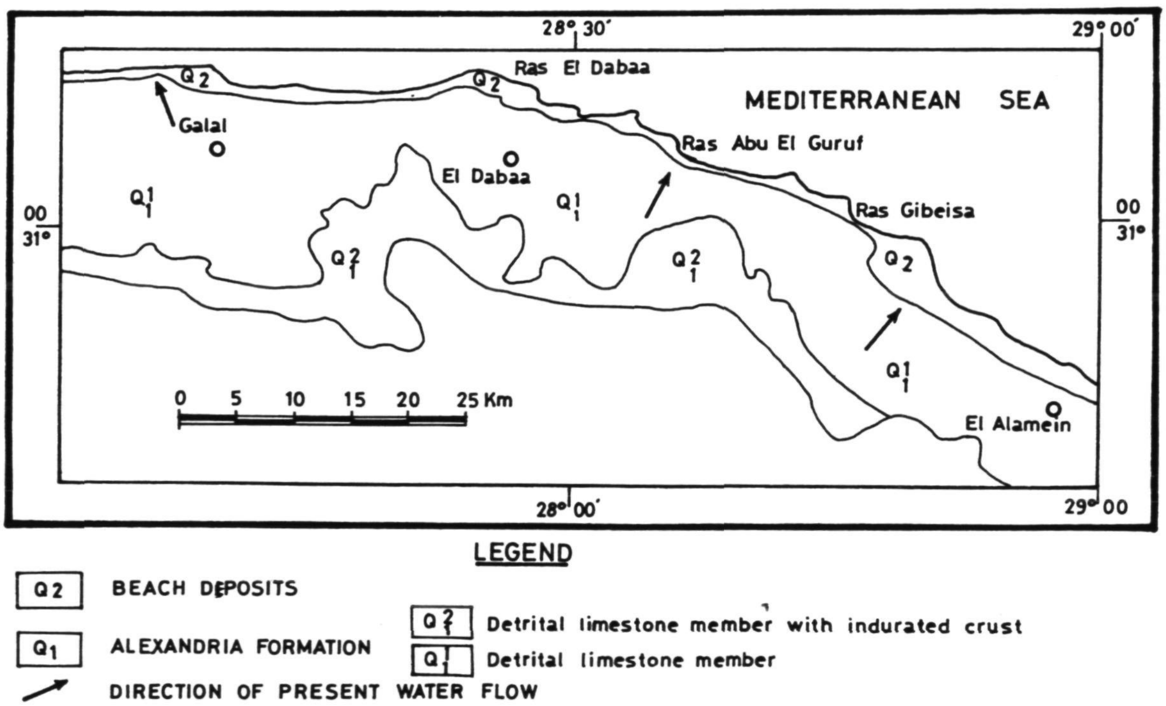

FIGURE 5. MEDITERRANEAN SEA LITTORAL AT EL ALAMEIN NEIGHBOURHOOD SHOWING THE WATER-BEARING ALEXANDRIA FORMATION.

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HYDROLOGICAL APPLICATIONS OF LANDSAT IMAGERY OF THE 1973 INDUS RIVER FLOOD, PAKISTAN

Morris Deutsch and Fred H. Ruggles, Jr.

U. S. Geological Survey
Reston, Virginia

Summary

During August 1973, the Indus River Valley of Pakistan experienced one of the largest floods on record, resulting in millions of rupees worth of damage to homes, businesses, public works, and crops. Tremendous areas of lowlands were inundated not only along the Indus River mainstem, but also along a number of major tributaries. The exceptionally high floods were primarily due to intense and widespread rainfall, which resulted from the convergence of moist air currents from the Arabian Sea and the Bay of Bengal. Flooding extended throughout the length of the valley, but cloud cover obscured flooding in the northern part of the valley from satellite observation. Landsat imagery, however, made it possible to depict the extent of flooding within an area of about 500,000 km^2 from south of the Punjab to the sea.

The Indus River data were used to continue experimentation in the development of rapid, accurate, and inexpensive optical techniques of flood mapping by satellite begun earlier in 1973 for the Mississippi River floods. The research work on the Indus River not only resulted in the development of more effective procedures for optical processing of flood data and synoptically depicting flooding, but also provided potentially valuable ancillary information concerning the hydrology of much of the Indus River basin.

The only Landsat data used for the experimentation were 70mm film negatives in each of the four bands of 13 scenes collected by the Landsat multispectral scanner during the period of flooding from September 1-4, 1973, and the 70mm negative for band 7 only of the same area when imaged under "normal" conditions in December 1972. For the optical analyses the original 70mm negatives were reprocessed so as to provide improved contrast between water and wet surfaces and surrounding dry areas on the scene. This process resulted in a new set of "contrast-stretched" 70mm positive transparencies which were then used exclusively in the study.

A distinct improvement in contrast between wet and dry areas was achieved by this procedure. However, vegetation, moisture conditions, terrane types, and land use all have their effects on film density, and hence are not readily interpretable from single band data. Compositing of the data from the various bands by the use of color filters permits the investigator to separate features such as water and vegetation by color--a so-called "color-coding." Two special composites were prepared from the reprocessed positives: by compositing band 5 in blue light, band 6 in green, and band 7 in red, morphologic and geologic features are enhanced, and water detail is well preserved. Areas of standing water appear as black or blue, wet or saturated soils as brown, and barren soils as buff or gray. Vegetation is strongly subdued and appears in tones of yellow. This rendition revealed considerable information of hydrologic significance; including broken or leaking canals, probable areas of ground-water discharge, leakage under a dam, areas of ponded water following recession of the floods, in addition to delineating the flood boundaries.

A mosaic, consisting of another special spectral composite of cloud-free images, was also prepared to assist those involved in river basin planning. Band 4 was projected in green light, band 5 in blue, and band 7 in red. Although this rendition tends to reduce contrast in the desert and unflooded vegetated areas, it maintains considerable geologic detail in the flooded areas, and greatly improves flood plain detail in comparison to the "standard" band 4 blue, band 5 green, band 7 red composite.

A temporal composite that vividly color-codes the flooded area in red was prepared by projection of the band 7 flood image in green and the band 7 pre-flood image in red. A mosaic of these composites showed the distribution of flooding over most of the basin. This rendition also shows excellent differentiation between dry soil, saturated soil and standing water. Where there was water in both the dry scene and in the flood scene the area is black, and the pre-flood channels of the major rivers are thus depicted in black. Where flooding occurred in areas where no water was present in the dry scene, the flooded area in excess of 20,000 km^2 is depicted in red. The mosaic revealed flooding of about 2,500 km^2 of agricultural and desert land caused by a breach of the main channel of the Sutlej River upstream from the Panjnad head works.