Geocarto International

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tgei20

Geoenvironmental assessment of the Mut wastewater ponds in the Dakhla Oasis, Egypt

Wael F Galal & Mahmoud H Darwish

To cite this article: Wael F Galal & Mahmoud H Darwish (2020): Geoenvironmental assessment of the Mut wastewater ponds in the Dakhla Oasis, Egypt, Geocarto International, DOI: 10.1080/10106049.2020.1856197

To link to this article: https://doi.org/10.1080/10106049.2020.1856197

Accepted author version posted online: 01 Dec 2020.

Submit your article to this journal

Article views: 1102

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tgei20

Check for updates

Geoenvironmental assessment of the Mut wastewater ponds in the Dakhla Oasis, Egypt

Wael F Galal*[1] **and** Mahmoud H Darwish[2]

[1]Geology Department, Faculty of Science, Assiut University, Assiut, 71516, Egypt

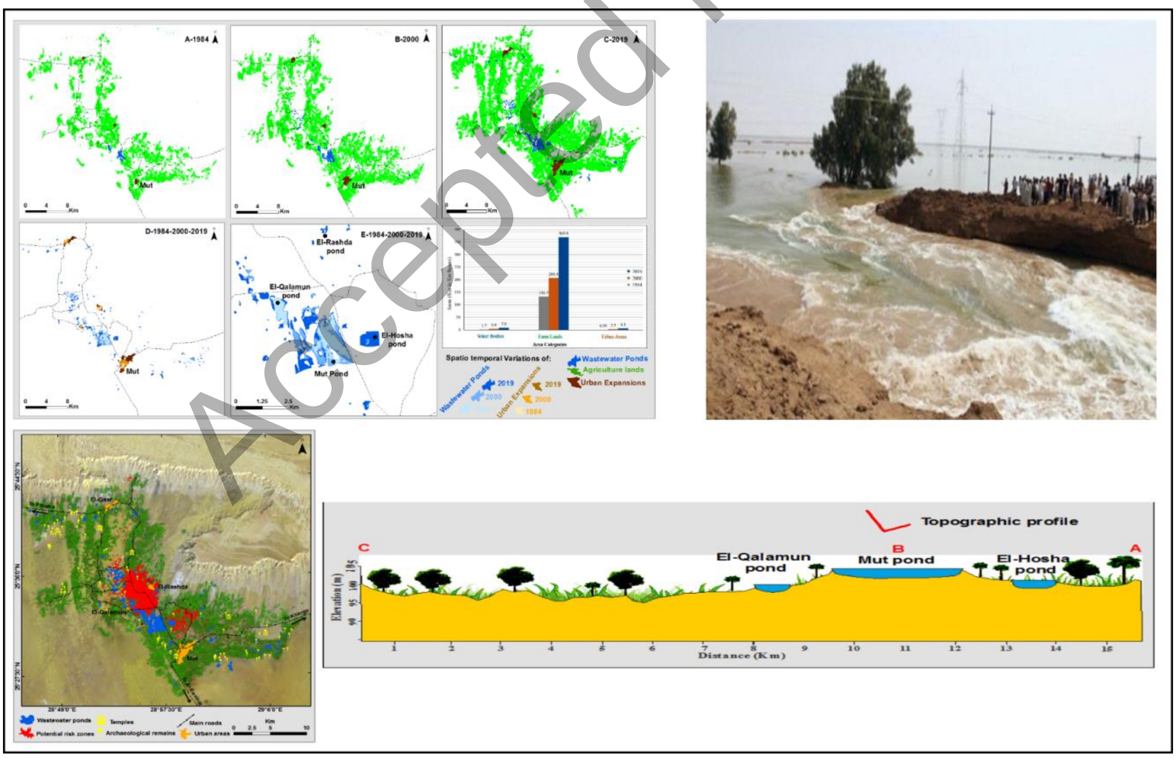
[2]Geology Department, Faculty of Science, New Valley University, El-Kharga, 72511, Egypt

*Corresponding Author: waelfathi70@Hotmail.com

Abstract

Disposal and accumulation of agricultural and sanitary wastewater in poorly engineered ponds in the Mut region, Dakhla Oasis of Egypt is a concern due to their poor water quality; significant expansion over a large spatial area, and their consequential impact on the environment. GIS and remote sensing were useful tools for determining spatiotemporal and the impact of wastewater ponds and land use/cover. The objective of this study is to map wastewater ponds and land use/cover changes over the period of 1984 to 2019. For this purpose, multi-temporal Landsat chronological images were used to assess the spatiotemporal activities. The findings indicated that the total area of wastewater bodies were about 1.79 km^2 in 1984, 3.92 km^2 in 2000, and 7.91 km^2 in 2019. This progressive spatial growth is a response to irresponsible usage of groundwater. Several environmental impacts were noticed, including depletion of the groundwater table, and soil salinization is one aspect of land degradation process. Finally, this study proposes implementation of a strict groundwater resource conservation act, preventing uncontrolled irrigation flooding and suggesting suitable low water consumption agricultural crops.

Graphical Abstract



Keywords: Geology, Groundwater, Environment, Wastewater ponds, Land Use/Cover, Hazard zones.

Accepted Manuscript

I Introduction

The study area of Mut and its surroundings is located in the Dakhla Oasis west of the Nile Valley. It lies between longitudes 28° $45^{\prime}46.92^{\prime\prime}$and 29° $09^{\prime}35.76^{\prime\prime}$East and between latitudes 25° $25^{\prime}07.51^{\prime\prime}$and 25° $48^{\prime}09.64^{\prime\prime}$North. The region includes four main ponds which are Mut, El-Qalamun, El-Hosha and El-Rashda plus some other inland spots scattered among the farmlands. The studied area is about 1641.9 km^2 and about 13.62 km^2 of it is occupied with wastewater accumulations, equal to 0.83% of the total region area (Figure 1). The Mut region is characterized by hyper arid climatic conditions, a high level of sunshine, and the average extreme daytime temperatures range from 44 to 50°C in summer, and 4 to 18°C in winter. Precipitation is about 0.07 mm/y, the rain is scarce but localized brief heavy downpours do occur in winter, the average evaporation rate is 24.3 mm/day and the main annual humidity is 40% (EMA, 2019).

The purpose of the current work is to detect and track the spatiotemporal wastewater accumulation and dynamic regime from 1984 to 2019 from geoenvironmental perspectives by using GIS and remote sensing. To do so, land use/cover changes in the area were traced with a special focus on the spatial relationship between wastewater ponds and their surrounding areas. However, the current study focuses on surface and subsurface geological factors controlling the pond site characteristics such as the bedrocks, faults, folds, groundwater levels and surface drainage patterns. Accordingly, this study is expected to assist with understanding of the future spatiotemporal and environmental potential impacts of wastewater ponds on existing close residential areas, industrial zones, farmlands, reclaimed lands, villages, as well as, on human health. It is worth noted that this research complements the study of Darwish and Galal (2020) on wastewater threats in the Kharga region.

To address the problematic issue of wastewater spatiotemporal impacts in the Mut region, it is necessary to understand and detect the spatial relationships between the wastewater and local activities. Agriculture and domestic wastewater collection systems in the Mut region and surrounding areas are a challenging issue. All wastewaters are consistently discharged throughout drainage facilities and accumulated in large, constructed artificial disposal ponds or flow in natural lowland spaces. The main four biggest ponds were created northwest and north of Mut City. These ponds are Mut with depths ranging from 1 to 2.5m, El-Qalamun and El-Hosha from 1 to 1.5m, and El-Rashda from 1 to 3m (MSA, 2019). It is remarkable that the Mut and El-Hosha ponds were constructed in areas relatively 4 meters higher than surrounding farms and villages, whilst El-Rashda pond in relatively lowland, and the El-Qalamun pond is a natural result of the general northwest slope of the area. On the other hand, these four artificial ponds were protected with weak, gravelly and sandy soil earthen dikes. The region is characterized by well-designed wastewater drainage networks into the main ponds, which collect both the rest of the sewage and all agricultural drainage water through conduits. There are 47 open surface collecting ducts and canals discharge wastewater to Mut pond with a total length of 183 Km, and 3 main open surface collecting canals with a length of approximately 7.9 km to El-Rashda pond (GAAD, 2019). It is observable that there are several inland natural accumulation areas randomly scattered, particularly among farmland and village areas in low elevations, such as those to the northwest, northeast, east and southeast of Mut City. Furthermore, to the northeast of Mut City, two sewage treatment plants were constructed. The first plant began operation in 2005 with a treatment volume of 12000 m^3/day, and in 2011, the second plant began operation with a capacity of 10000 m^3/day to mitigate domestic sewage (MSA, 2019).

One of the worst, disastrous failure events happened at El-Owinah village in winter 1996, when the wastewater level in the Mut pond rose above the berms, inundated the crop fields and destroyed more than 300 houses in the surrounding villages. These events repeated again in winter 2014, damaged the local infrastructure and flooded the depressions of natural spillway areas with wastewater. Likewise, in winter 2015 and 2017 earth dikes of the El-Rashda pond collapsed and

Accepted Manuscript

heavy floods of wastewater reached some residential areas in the El-Hindaw village destroying many farms and houses (Figure 2). These harmful events are common and repeat yearly, especially in winter months, as the constructed ponds have reached their full capacity due to the intensive discharge of wastewater and cannot accommodate any further volume. Certainly, this continued increase in the huge volume of accumulated wastewater in the region, will cause a negative environmental impact on the region's development. Moreover, these ponds are disadvantaged for use because they contain large amounts of unsuitable, highly salted and polluted water that can't be used in traditional practices unless further managed in innovative ways.

II Geological context

The geological setting of the Dakhla Oasis has been the subject of different detailed investigations e.g., Attia (1970), Barthel and Herrmann-Degen (1981), Hermina *et al.*, (1961), Hermina (1990), Said (1990) and Ghoubachi (2001). In brief, the exposed sedimentary succession in the study region ranges in age from Late Cretaceous to Quaternary. These rocks are represented by Maghrabi, Taref, Mut, Dawi, Dakhla, Tarawan, and Garra formations, and Quaternary deposits (Figure 3). The Nubia sandstone, composed of sandstone and claystone is directly underlain by the basement rocks and represented with Maghrabi and Taref formations. The Maghrabi Formation is occupying the southeastern corner and composed of marine shale and claystone. The Taref Formation overlying the Maghrabi Formation, is mainly composed of fine to medium grained and well sorted sandstone with a few shale interbeds. The Mut Formation overlies the Taref Formation and extensively covers the surface of the study region, consisting of variegated shale, siltstone, flaggy sandstone, ferrigenous and reddish claystone with thickness decreasing towards the east and the south where the Taref Formation is exposed on the surface. The Mut Formation, topped by a sequence of the Dawi Formation, consists of a phosphate-bearing unit alternating with black shale and limestone. The top of the Dawi Formation is covered by dark-grey shale, marl, and clay with intercalations of calcareous sandy and silty beds known as the Dakhla Formation. The Tarawan Formation overlies the Dakhla Formation and is composed of fossiliferous, partly marly, or chalky, yellowish white limestone grading into limestone, impure limestone, or dolomite. The Garra Formation located above the previous layers is characterized by white, thick-bedded, chalky limestone beds. The Quaternary deposits are widespread on the region floor, including the eolian sediments of frequent sand dunes with mainly NW-SE stretches, sand sheets, and playa deposits that are rich with plant remains.

From the structural point of view, the sedimentary formations covering the region dip gradually northward at a very small inclination, while the Dakhla depression, considered a low area, occurs between major structural highs. The depressions are considered a major syncline, and generally the region is affected by folds and faults, which oriented in the NE-SW and NW-SE directions. The Mut region is influenced by two major folds, the Mut syncline and El-Qasr anticline folds. Both axis are parallel, extending in NE-SW directions, and characterized by gentle slopes.

III Geomorphological setting

Generally, the Dakhla region is composed of three main geomorphological units, a high steep scarp in the north and northeast, a depression in the middle, and a structural plain in the south (Ghoubachi, 2001, Brookes, 1993). The high plateau bounds and overlooks the Mut region to the north and northeast and is characterized by an irregular outline, a wide rough surface extending in a WNW-ESE direction and a precipitous escarpment dipping northward. The height of this scarp ranges from 542 m to the Mut northeast and decreases gradually to reach about 404 m northwest of El-Qasr City, forming a gradual slope up to the plateau. Mut, El-Qalamun, El-Rashda, and El-Qasr Cities are sited in a depression of an immense lowland containing diverse landforms such as frequent hills, terraces, and piedmont flats. It is noticeable that the depression floor is signified by semi-flat topography varying from 81 m in elevation at Mut, El-Qalamun and west of El-Rashda to less than

Accepted Manuscript

30 m towards northwest near El-Qasr City. It is observable too that this flat plain gradually continues southwest and southward into a higher structural plain bordering the Mut region depression and extending as an extensive elevated plain varying in elevation from 30 m to 255 m and sloping northward.

IV Hydrogeological setting

The Mut region mainly depends on groundwater supplies as the single source of water demands for domestic and irrigation purposes. The Nubian sandstone with an average thickness of about 1500 m, is the main source of groundwater in the region. It is divided into three main subsurface water-bearing layers separated by three alternative clay layers (Thorweihe and Heinl, 1993). The Taref sandstone is represented as the shallow water-bearing formation in the Mut region, with 110 m average thickness, and water levels ranging from 60 to 120 m below the ground surface, and salinity ranging from 133 to 909 mg/L. On the other hand, due to the water having been heavily exploited since the 1960s, a decline in the groundwater level and an increase in the salinity have been recorded (Gad *et al.,* 2011).

It is worth to mention that the population of the Mut region increased from 28777 in 1984 to 63826 in 2019 with approximately 48.2% females. According to population census 2019, the total population of the main cities constituted 46.7% of the total province population CAPMAS (2019). The region's spatiotemporal geographic status, inhabitant's behavior and rural communities is a dynamic over the last decades due to groundwater abundance. Remarkably, some village residents are contending with shallow groundwater decline and well shortages, and some rural communities have abandoned the area and migrated. Generally, the residents moving towards the central part of the Mut region where plenty of water wells and reclaimed lands.

Intensive well drilling recorded over the periods from 1984 to 2019, is represented by two main well types, shallow and deep wells (Figure 4). There are about 1182 shallow wells drilled by local residents, with depths ranging from 85 m to 120 m. Additionally, 161 deep wells were drilled by the government with depths ranging from 550 to about 1200 m, and lately these numbers have increased rapidly. The static-water table of the wells ranges from 4.9 to 13.4 m, with an average total discharge of 895608 m^3/day (GAG, 2019). A significantly huge number of wells has been observed with small distances between them, and an estimated well density of 1 well for each approximately 280 m^2. This must surely have negative implications on the discharge rate of water and hence, the decline of the water table. Distance between wells should be controlled, and pumping should be managed to permit aquifer equilibrium. Therefore, the suggested safe distances between the drilled wells should not be less than 1 Km to avoid any discharge shorting (Sharaky *et al.,* 2017).

Regarding the Mut region water quality, the Total Dissolved Salts (TDS) and the Sodium Adsorption Ratio (SAR) values in water are important indicators for determining the degree of water quality and suitability for different uses. These salts originate from natural sources such as soil and rock bearing zones or from anthropological sources like sewage and agricultural drainage.

Some selected scattered water samples were collected from groundwater wells and wastewater ponds, representing an example of the different water categories in the study area, to evaluate the water suitability (Figure 4). According to the World Health Organization (WHO, 2011) and the U.S. Salinity Laboratory (1954) classifications, the Mut region groundwater is in the range of fresh water, where the TDS values range from 190 to 450 mg/L, and SAR values from 1 to 3. The hydro-chemical assessment indicated that the extracted groundwater is suitable for drinking and irrigation purposes. On the other hand, the water samples collected from Mut pond, an agricultural wastewater mixed with sewage, and El-Qalamun pond, an agriculture wastewater only, indicate very high values of both TDS and SAR. The analysis results mean that the ponds water's are unfit for any use, therefore any seepage will lead to long-term soil alkalinity and land degradation (Table 1).

Accepted Manuscript

V Materials and methods

To attain the objectives of this study, field surveys were carried out in the Mut district in 2019 March and July, for field reference data collection including the accumulation ponds, wastewater plants, groundwater wells, and some surrounding farmlands. The data sets were assembled by applying remote sensing and GIS frameworks. Multi-temporal data of Landsat-5 TM, Landsat-7 ETM+, Landsat-8 OLI, and Sentinel-2 which were issued by USGS (1984, 1999 and 2019) respectively were used in this study to extract the areal evolution of the agriculture, residential and water body areas. According to Borana *et al.,* (2019) and Wang *et al.,* (2017), the 30 m spatial resolution Landsat-8 bands are downscaled to 10 m, treating the 10 m Sentinel-2 bands and 15 m Landsat-8 Pan Sharpen (PAN) band as covariates. ALOS PALSAR digital elevation model (DEM) with a 12.5-meter resolution were obtained from JAXA and processed by Alaska Satellite Facility (ASF DAAC), 2015 was used to obtain high-resolution digital topographic, variation of elevation and watershed maps.

The Normalized Difference Vegetation Index (NDVI) techniques were applied to extract the agriculture areas and to predict all changes that occurred in the vegetation lands. NDVI was calculated from the red and the near-infrared (NIR) bands for each sensor type, according to the equation of Rouse *et al.*, (1974). Likewise, The Normalized Difference Water Index (NDWI) method that uses the green and near-infrared (NIR) bands was applied according to the equation of McFeeters (1996) to outline the water bodies. However, for the accuracy of the obtained results, the maximum likelihood technique (supervised classification technique) was used (Richards and Jia, 2006), to extract all obtainable data from the agricultural areas and bodies of water. The results of NDVI, NDWI and supervised classification were matched with each other and with the original images. The area of the total vegetated lands and water bodies for each period was calculated and the spatiotemporal change was determined.

Additionally, a geological map of Egypt issued by the EGPC and CONOCO Coral (1986, 1987) was used. Several statistical data sets obtained from AA (2019), AHU (2019), EMA (2019), GAAD (2019), GAG (2019), MSA (2019) of the Dakhla offices and SWERI (2019) were considered. All the images, maps and data sets were digitized and projected to WGS-84 of the Universal Transverse Mercator System (UTM) with geographic coordinates. ESRI ArcGIS 10.5 (2017) and PCI Geomatica (2018) were used to interpret and model the obtained data.

VI Results and discussion

5.1 Topography

The topographic factor exerts a strong influence on wastewater pond spatial distributions and delineating the probable course of wastewater flow and accumulation spots (Figure 5). The results extracted indicated that the slope was the major topographical factor that affected wastewater accumulation and flow regime in the Mut region. However, the effect of topographical factors on wastewater development was assumed affecting not only wastewater but also rainwater and flash floods, thereby directly impacting the nearby ponds.

The obtained results revealed that most lowlands are located in the centre of the region extending NW-SE and that most of the agricultural wastewater flows in this path. The slopes generally range from 2.6 in flat plains reaching to 82 degrees in steep areas; the main inhabited areas are located in flat or semi-flat low terrains. Since slope influences the runoff process, in case of large volumes of wastewater diverted from pond collapse or heavy rainstorms, downslope flooding could create a hazard zone. For this reason, wastewater accumulation areas having slopes of more than 10% were considered as potentially highly unsafe to contaminant runoff (Aydi *et al.,* 2016).

5.2 Surface waters

Accepted Manuscript

The extraction of stream networks and subcatchment boundaries carried based on the most widely used D-8 algorithm proposed by O'Callaghan and Mark (1984), and Maidment (2002). The output results showed the spatial relationships between the wastewater ponds and the streams or drainage catchments, runoff and flood forecasting, and can also be used as a guide for wastewater management. The analysis revealed the surface stream network of each main wastewater pond and the large waste swamps, to forecast the potential risks and likelihood of heavy runoff and flash floods. Fourteen subcatchments were defined, as shown in Figure 6, and each one has a different size, shape and drainage pattern. The drainage systems prove that artificial wastewater ponds were incorrectly located and are constructed either inside or at the outlets of catchment zones. Remarkably, Mut, El-Hosha, El-Qalamun, and El-Rashda, which have the largest subcatchment area, are also incorrectly sited.

Retention of huge amounts of wastewater is very risky, as the storage ponds could be breached by the torrential flows. In occurrences of heavy rainfall, the low soil infiltration rate that rainwater passes through the streams could cause destructive flash floods and could also overrun the wastewater pond's capacities. Such phenomena happened numerous times in winter 1996, 2014, 2015 and 2017 when the wastewater and contaminants flooded the territories around the ponds (Figure 2). Unfortunately, the agricultural drainage systems in the region were designed without sustainable plans and the natural rain watercourses and floodplains were certainly not taken into account.

Overall, this significantly devastating hazard to the area requires integrated control and mitigation strategies considering the geological and hydro-geomorphological aspects in relation to the spatiotemporal conditions of the existing or potential new wastewater ponds. The strategy should keep the outflow at pre developmental levels and more efficiently use the capacity of the ponds.

5.3 Land use/cover

For this study Landsat time-series imageries are used over 3 periods from 1984 to 2019. The evolution detects the spatiotemporal changes of the Mut region and its surrounding environment over 35 years (Figure 7 A-C). Results specified that two stages characterize the growths in the region, a low rising stage before the 2000s, marked by less development; and a high-rise stage, distinguished by a rapid development rate after the 2000s. Generally, the evaluation of land use/cover revealed that agricultural practices have significant spatial progressions through the studied time period.

The analysis of the Landsat images shows that there were four main ponds in the Mut region and some distributed small inland accumulation areas, the total number of wastewater bodies rapidly increased during the study period from 13 in 1984 to 45 in 2000 and then to 154 in 2019, this was matched by the progressive increase in farmland and population lands (Figure 7 D). The specific spatiotemporal detailed analysis of the four main wastewater ponds illustrated that the pond areas increased from 1984 to 2000, and relatively significantly increased from 2000 to 2019. Mut pond is the oldest and biggest one; it was 1.13 km^2 in 1984, to 2.37 km^2 in 2000 then 3.6 km^2 in 2019, which is equal to 73.55% of the total four wastewater ponds area. El-Qalamun pond was 0.4 km^2 in 1984, then 0.45 km^2 in 2000 to 0.74 km^2 in 2019. El-Hosha pond not recorded in 1984, it was 0.02 km^2 in 2000 to 0.52 km^2 in 2019. El-Rashda pond is not noted in 1984 and 2000 because it was created after the 2000s and appeared with 0.035 km^2 in 2019 (Figure 7 E).

The spatiotemporal and remote sensing analysis clarified that the increases in agriculture areas from 1984-2000, were from 132.77 km^2 to 206.45 km^2, and the area then expanded rapidly to 368.81 km^2 in 2019. On the other hand, the urbanized lands also stretched due to the increasing population from 0.954 km^2 in 1984 to 2.51 km^2 in 2000, and then significantly occupied 6.1 km^2 in 2019. According to the results obtained, one of the most marked negative signs of spatiotemporal change is the harmful drastic increase of wastewater bodies, which implies an increase in area

Accepted Manuscript

coverage. The total wastewater areas were 1.79 km^2 in 1984 to 3.92 km^2 in 2000 then expanded to 7.91 km^2 in 2019 respectively, (Figure 7 F and Table 2).

Over the period observed, it is noticeable that the land use/cover detection predicts increased water consumption and extra wastewater generation in the future. This information will aid as a vital tool in the region's management and mitigation plans.

5.4 Agricultural crops

The agricultural crops in the study area vary between winter, summer and delayed summer crops in addition to horticultural crops. The data obtained from the AA (2019) and SWERI (2019) showed that the average water consumption of main crops is about 3162.5 m^3/feddan which varies from crop to crop. Winter crops occupy 64% of the total cropped area, characterized by a low water consumption rate of 2110.3 m^3/feddan, and are represented by wheat, alfalfa, barley, beans, and vegetables. Summer crops come in second place in the cropped area by about 24%, the most important crops being alfalfa, sorghum, pumpkin seeds, and vegetables with an average water consumption of 3250 m^3/feddan. The delayed summer crops represent 4% of the area, and are maize, sweet corn, and grains used for livestock feeding. Horticulture occupies the third place by 8%, represented by palm trees, citrus, mango, and olives, with an average water consumption of 5430 m^3/feddan during the year. Alfalfa, fruit and wheat crops represent the predominant crops in the Mut region after rice, due to its economic importance although it has high water consumption rates. Alfalfa is the heaviest water-consumption crop with 6850 m^3/feddan during the year. As detected, there is an abundance of agricultural areas, cultivated grass and grain crops and high populations. The number of livestock and domestic birds is 178100 and 293469 respectively in the year 2010, with relative increases of 22% recently (AA, 2019).

The cultivation practices of the Mut region are principally dependent on groundwater resources in crop irrigation with a ratio of 97%, followed by 2.8% on the reuse of agricultural wastewater and 0.2% on sewage water. It is documented that 66% of the cultivated area is irrigated by the flood system, with the rest by modern techniques (GAAD, 2019).

The foregoing observations reflect that the spatiotemporal expansion of wastewater ponds and inland accumulations corresponds to the abundance of groundwater wells and heavy exploitation of the water resources in cultivation using traditional irrigation systems.

The unmanaged surplus flow of wastewater into remote areas has encouraged the farmers to cultivate crops regardless of quality and source of water used in irrigation. Indeed, the current improper surface irrigation pattern causes high water losses, the decline in land productivity, waterlogging and salinity problems. Accordingly, seepage of the cultivated areas adversely affects other low vicinity areas. Moreover, these unsustainable practices have, in their turn, harmful effects on the region's irrigated crops and land degradation rates.

Accepted Manuscript

VII Geological influences

Geology plays an important role in the spatiotemporal evolution of wastewater ponds and the shaping of surrounding spaces, as well as on the impact of these ponds and the future environment of the region. Geology varies across the study region and the extensive surface bedrock of the depression floor is mainly composed of the Mut Formation which accommodates most of the existing ponds. Also, it is observable that sand dune belts and playa deposits are bounding the wastewater ponds in some localities, as in the Mut, El-Hosha, El-Qalamun and El-Rashda ponds hence, the surface bedrock soil is the essential geologic factor controlling the wastewater accumulation and is responsible for its flow regime.

The porosity parameter of the bedrock is the main geological factor that should be considered in the evaluation impact of wastewater ponds. The measured total effective porosity of the bedrock samples in the Mut region ranges from 8.5% to 16.8%, with a mean value of 12.65%. These differences in the porosity values can be related to the variations in grain size, matrix cementation and the diagenesis processes that affect the soil grains (Mahmoud and Ghoubachi, 2017). Notably, the surface soil quickly becomes fully saturated with the wastewater because it is underlain by impermeable layers. According to El-Shater *et al.*, (2019), the Mut region and surrounding surface soils consist of four shallow subsurface layers; dense green gypsiferous shale grading downward into very hard yellowish-green shale, dense dark greenish shale, and reddish-gray shale and all being underlain by an impermeable layer rich with calcium carbonate content at depths of 10 m below the ground surface. Consequently, waterlogging is a common feature and deep percolation into soil layers does not occur. Also, it is observed that the excess irrigation water accumulates on top of the surface layer, forming inland waste swamps as a result of lateral seepage in lowlands with a very shallow water table beneath the ponds.

Additionally, this lateral seepage increases soil salinity, which is debilitating the crop productivity in surrounding areas. The poor surface porosity however has a very good influence on the region, as it decreases the possibility of wastewater leakage from collecting ponds and inland accumulation areas down into the shallow Nubian aquifer, preventing groundwater pollution. The main precaution that should be considering is faults, in order to prevent wastewater infiltration downward towards the groundwater aquifer. The geologic map of the study area shows that there are numerous sets of surface faults cutting and surrounding the Mut and El-Qalamun ponds in SW-NE, E-W and SE-NW directions.

VIII Vulnerability and risk map

The assessment risks map of wastewater accumulations was developed by combining parameters associated with geological and terrain factors, such as soil or bedrock type, slope, flood plain, drainage or stream network, groundwater wells, urbanization, farmlands, and the various existing infrastructure. The overall goal of the risk map is to provide information on the present and the potential overflow and spillover extent of wastewater accumulation ponds and their impacts on residential and farmlands, which is essential for mitigation and management.

The obtained predictive risk map finds three main sectors across the Mut region with the highest probable hazards, these zones account for 45.62 km^2 or approximately 12.17% of the total inhabited areas of the studied region. It is obvious that the most critically risky zones that should be focused on are located on the strip to the northeast of Mut City, around the Mut, El-Hosha and El-Qalamun ponds northeast towards El-Qasr City. Moreover, other impending risky zones are estimated to exist widely, such as to the east and southeast of Mut City at the southeastern portion of the region. The Mut region is rich with precious archaeological and heritage sites, about 91 archaeological remains sites, and six main temples and buildings were recorded so, it is necessary for monitoring the sites and establishing protective action against any wastewater seepage or flow (Figure 8).

Wastewater is able to rabidly infiltrate through faults, fractures, and cracks which are dominant and frequent in the region hence, serious action should be taken to avoid unnecessary negative spatial effects of the wastewater ponds on the precious groundwater resources in the region. Similarly, leakage from the wastewater ponds and the collecting ducts leads to the infiltration of irrigation-return flows in surrounding farms (Darwish and Galal, 2020).

IX Conclusions and recommendations

Accepted Manuscript

The formation of wastewater is mainly due to the rapid expansion of agricultural and urban agglomerations that have put tremendous stress on the studied region. The results detected an intense proliferation and rapidly changing trend in the wastewater ponds and accumulation surface areas, in 1984, the total areas were 1.79 km^2, in 2000, it was 3.92 km^2, to be 7.91 km^2 in 2019. The trend of increasing ponds areas portrays a strong relationship with the agricultural and residential activities indicating a strong impact of anthropogenic activities on the ponds. If such a trend continues, where the excess intensive irrigation water recharged to the ponds is higher than the capacity, this will lead to a substantial rise of the wastewater levels, there will be an extreme waste overflow and flooding of the surrounding lowlands. The results revealed that 45.62 km^2 of the Mut region inhabited lands qualify as high-risk zones and are unsuitable for future development.

The study revealed that the increase in drilling water wells for the purpose of agricultural expansion leads to an increase in the areas of wastewater ponds because of using traditional irrigation methods. The continuation of this situation leads to more problems in these ponds unless the matters are addressed by rationing the drilling of water wells and using modern irrigation methods with the cultivation of suitable crops.

The study showed that there is no possibility of contamination of the saturated groundwater bearing zone with the wastewater of these ponds, due to the presence of a Mut formation, which characterized by low porosity and permeability which prevents vertical infiltration. However, the continuation of lateral infiltration will lead to soil salinization and land degradation. The possibility and risks of vertical infiltration of wastewater into the underground water will remain, especially with the presence of cracks and faults in the places of these ponds. Consequently, geological constraints must be strictly taken into account either for setting new wastewater ponds or for any future spatial extensions to the existing artificial ponds.

Through this study, it became clear that most main wastewater ponds are located on stream outlets or inside floodplains in big catchment areas so the stream drainage networks must be taken into account and some mitigation facilities should be designed to avoid any unexpected flash floods.

One such applicable recommendation regarding the undesired bounty of wastewater is to possibly control the cultivation of voracious water crops. Therefore, cultivating woody trees and some aquatic plants can be an effective attempt at relieving the contamination from existing ponds, as they have the potential to remove the pollutants from wastewaters. Considering sustainable aspects, the pond areas can be utilized as an ecological park for birds, and for tourism activities whilst considering the aesthetics and recreational value.

Finally, this study provides quality assessments for the long-term monitoring of wastewater status in order to achieve an optimum sustainable management plan for the Mut region and to minimize the associated environmental impacts.

Acknowledgements

The authors are grateful to the Editorial and publishing team for all guidance. We wish to thank and appreciate the anonymous reviewers for their valuable comments. Our thanks to all administrations which offered the archived data.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

Accepted Manuscript

The authors received no financial support for the research, authorship, and/or publication of this article.

REFERENCES:

AA (2019): Agriculture Administration, Ministry of Agriculture and land Reclamation, the Dakhla office, (Internal reports).

AHU (2019): Administration of Housing Utilities, Ministry of Housing Utilities and Urban Developments, the Dakhla office, (Internal reports).

ASF (2015): Alaska Satellite Facility, Radiometric Terrain Corrected Products-Algorithm Theoretical Basis Document, ASF: Fairbanks, AK, USA. https://doi.org/10.5067/Z97HFCNKR6VA

Attia, S. H. (1970): Subsurface Geology of El-Dakhla Oasis. M. Sc. Thesis. Faculty of Science, Cairo University, Cairo, Egypt.

Aydi, A., Abichou, T., Hamdi Nasr, I., Louati, M. and Zairi, M. (2016): Assessment of land suitability for olive mill wastewater disposal site selection by integrating fuzzy logic, AHP, and WLC in a GIS. Environ. Monit. Assess., 188:59. https://doi.org/10.1007/s10661-015-5076-3

Barthel, K. W. and Herrmann-Degen, W. (1981): Late cretaceous and early tertiary stratigraphy in the great sand sea and its SE margins (Farafra and Dakhla Oases), SW Desert, Egypt. Mittl. Bayer. Staatssamml. fur Palaontologic Hist. Geol. 21, pp. 141-182.

Borana, S. L., Yadav, S. K., Parihar, S. K., and Kaplan, G. (2019): Pan-Sharpening of Landsat-8 Using Synthetic Sentinel-2 PAN Data. Esri India User Conference, August 28-29.

Brookes, I. A. (1993): Geomorphology and Quaternary geology of the Dakhla Oasis region, Egypt. Quaternary Science Reviews, 12, pp. 529-552. https://doi.org/10.1016/0277-3791(93)90068-W

CAPMAS (2019): Central Agency for Public Mobilization and Statistics (CAPMAS), annual report, Cairo, Egypt. Statistical Year Book, Issue No (120), Ref. No. 71.01111.2019.

CONOCO (1986, 1987): Geological map of Egypt (scale 1: 500,000), compiled by the EGPC and CONOCO Coral, Cairo, Egypt.

Darwish, M. H. and Galal, W. F. (2020): Spatiotemporal effects of wastewater ponds from a geoenvironmental perspective in the Kharga region, Egypt. Progress in Physical Geography: Earth and Environment. Vol. 44 (3), pp. 376-397. https://doi.org/10.1177/0309133319879321

El-Shater, A., Khashab, M. A, El-Sherif, M. A. and Abu Seif, E. S. (2019): Geological and Engineering Characteristics of Expansive Soils in Western Desert, Egypt. Civil Eng. Res. J., 7(2). https://doi.org/10.19080/CERJ.2019.07.555707

EMA (2019): Egyptian Meteorological Authority, The climatic atlas of Egypt. Available at: https://www.emaeg.org/?lang=en.

Accepted Manuscript

ESRI (2017): ArcGIS 10.5 Desktop, Environmental System Research Institute, Inc. Redlands, California, USA.

GAAD (2019): General Administration of Agriculture Drainage, Ministry of Water Resources and Irrigation, the Dakhla office, (Internal reports).

Gad, M. I., El Sheikh, A. E. and El-Osta, M. M. (2011): Optimal management for groundwater of Nubian aquifer in El Dakhla depression, western Desert, Egypt. Int. J. Water Resour. Environ. Eng. 3 (14), pp. 393-409. https://doi.org/10.5897/IJWREE11.103

GAG (2019): General Administration of Groundwater, Ministry of Water Resources and Irrigation, the Dakhla office, (Internal reports).

Ghoubachi, S. Y., (2001): Hydrogeological Characteristics of the Nubia Sandstone Aquifer System in Dakhla Depression, Western Desert Egypt. M. Sc Thesis. Faculty of Science, Ain Shams Univ., 260 p.

Hermina, M. H. (1990): The surrounding of Kharga, Dakhla and Farafra oases. In: Said, R. (Ed.). The Geology of Egypt. Balkema, Rotterdam, Brookfield, the Netherlands, Ch. 14, pp. 295-292.

Hermina, M. H., Ghobrial, M. G. and Issawi, B. (1961): The Geology of Dakhla Area. Ministry of Industry, Geological and Mineral Resources Department, Cairo, Egypt, 33 p.

Mahmoud, H. H. and Ghoubachi, S. Y. (2017): Geophysical and hydrogeological investigation to study groundwater occurrences in the Taref Formation, south Mut area, Dakhla Oasis, Egypt. Journal of African Earth Sciences 129, pp. 610-622. http://dx.doi.org/10.1016/j.jafrearsci.2017.02.009

Maidment, D. (2002): ArcHydro GIS for Water Resources. ESRI Press, Redlands, CA.

McFeeters, S. K. (1996): The use of the normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7), pp. 1425-1432. https://doi:10.1080/01431169608948714.

MSA (2019): Municipal Sewage Authority, Dakhla, the New Valley Governorate, Egypt, (Internal reports).

O'Callaghan, J. F. and Mark, D. M. (1984): The Extraction of Drainage Networks from Digital Elevation Data. Computer Vision, Graphics and Image Processing, 28, 328-344. http://dx.doi.org/10.1016/S0734-189X(84)80011-0

PCI Geomatica (2018): PCI Geomatics Enterprises, Inc., 90 Allstate Parkway, Suite 501, Markham, Ontario, Canada L3R 6H3.

Richards, J. A. and Jia, X. (2006): Remote Sensing Digital Image Analysis: An Introduction, 4th ed., Springer: Secaucus, NJ, USA, 439 p. https://doi:10.1007/3-540-29711-1

Rouse, J. JR., Haas, R., Schell, J. and Deering, D. (1974): Monitoring Vegetation Systems in the Great Plains with ERTS, NASA, Goddard Space Flight Center 3d ERTS-1 Symp 1, Sect A: Greenbelt, MD, USA, pp. 309-317.

Accepted Manuscript

Said, R. (1990): The geology of Egypt. A. A. Balkema, Rotterdam, Netherlands, ISBN 9061918561, 734 p.

Sharaky, A. M., El Sayed, A. E. and Shanab, E. F. (2017): Groundwater Assessment for Agricultural Irrigation in Toshka Area, Western Desert, Egypt. In: Negm, A. M. (ed) Conventional Water Resources and Agriculture in Egypt. Handbook of Environmental Chemistry, Springer International Publishing AG. https://doi:10.1007/978-3-319-95065-5

SWERI (2019): Soils, Water and Environmental Research Institute, Water Requirements and Field Irrigation, Ministry of Agriculture and land Reclamation, Cairo, Egypt, (Internal reports).

Thorweihe, U. and Heinl, M. (1993): Groundwater resources and Management in SW Egypt. Catena Supplement, Biomineralization process of Iron and Manganese, Berliner geowissenschaftliche Abhandlungen 26: pp. 99-121.

USGS (1984, 1999 and 2019): The United States Geological Survey, Earth Resources Observation and Science Data Centre (EROS), (http://eros.usgs.gov).

U. S. Salinity Laboratory (1954): Diagnosis and improvement of saline and alkaline soil. US. Dep. of Agriculture, USDA, Washington, USA. Handbook No. 60, 160p. https://www.ars.usda.gov/pacific-west-area/riverside-ca/us-salinity-laboratory/

Wang, Q., Blackburn, G. A., Onojeghuo, A. O., Dash, J., Zhou, L., Zhang, Y. and Atkinson, P. M. (2017): Fusion of Landsat 8 OLI and Sentinel-2 MSI Data. IEEE Transactions on Geoscience and Remote Sensing Vol. 55, Issue 7, pp. 3885-3899. https://doi:10.1109/TGRS.2017.2683444

WHO (2011): World Health Organization. Guidelines for drinking-water Quality. Recommendations.4th Ed., Geneva, Switzerland, ISBN, 978-924. pp. 219-443.

Accepted Manuscript

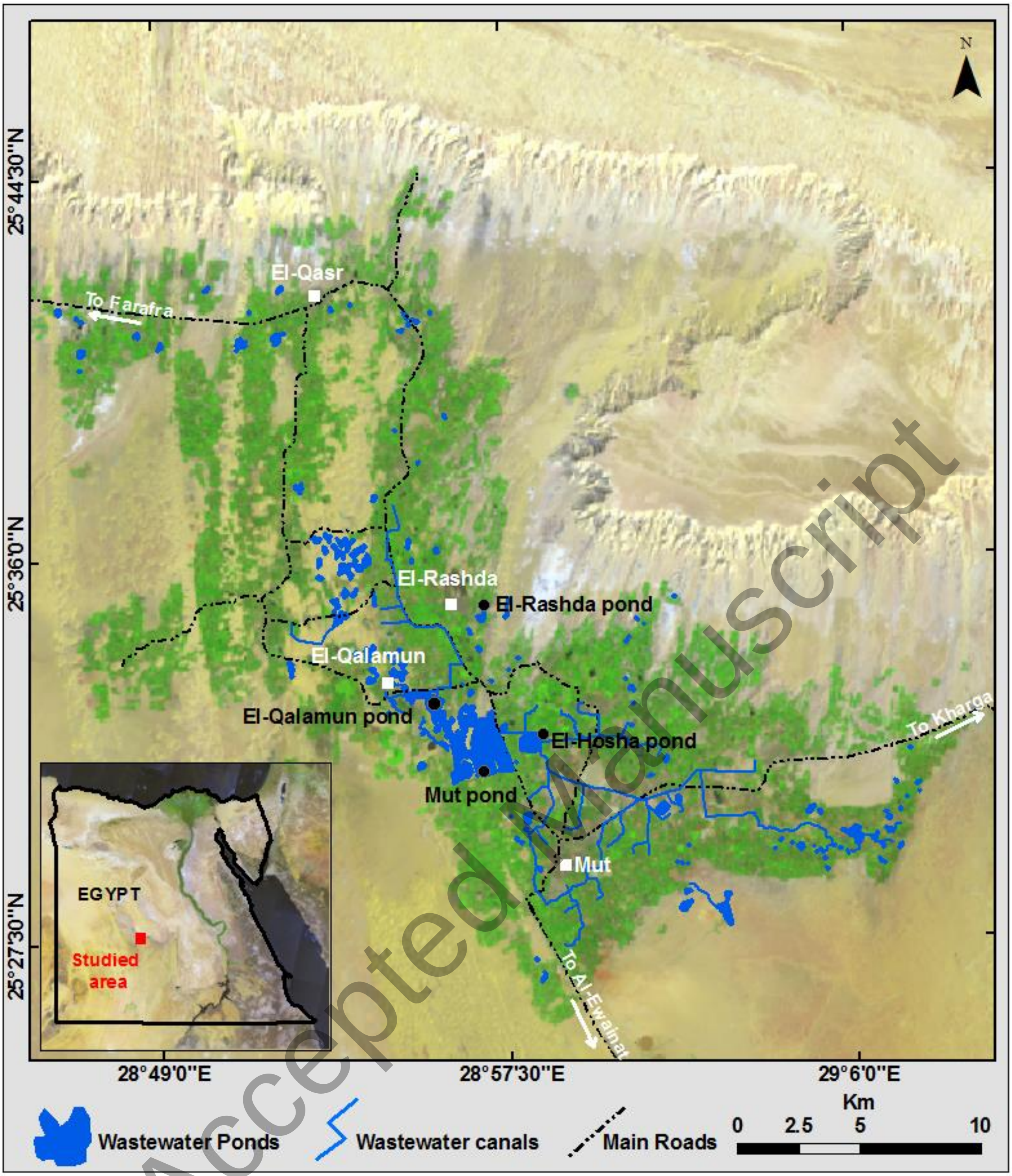


Figure 1. Location map of the wastewater accumulations in the studied area.

Accepted Manuscript

Figure 2. Field photos show: (A) Mut pond. (B) El-Qalamun pond. (C & D) Flooding of wastewater due to the collapse of the pond earth dikes. (E & F) Wastewater flooding the housing areas. (G) Wastewater flooding the farmlands. (H) Soil salination.

Accepted Manuscript

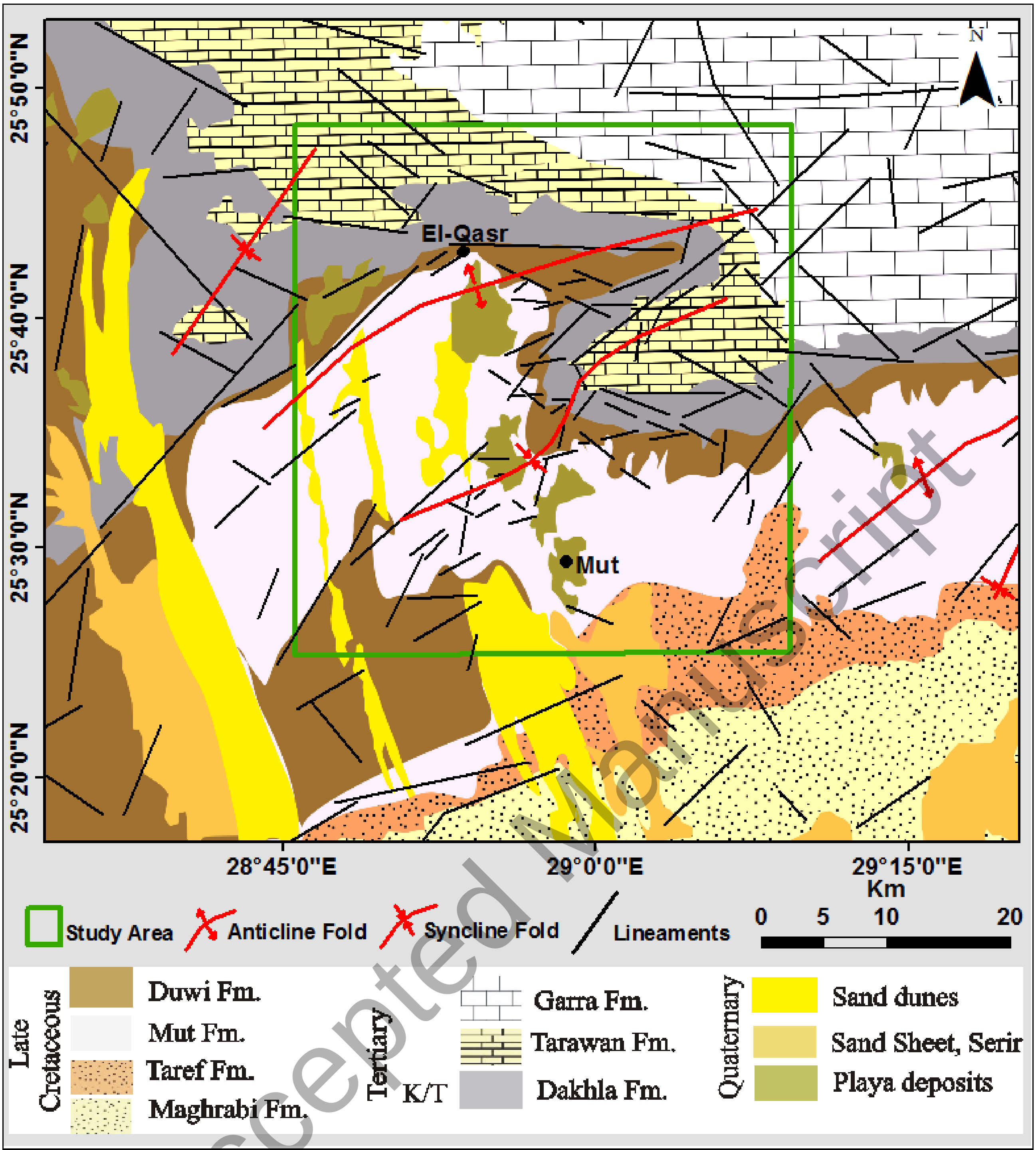


Figure 3. Geological map of the studied area (modified after CONOCO, 1987 and Hermina, 1990).

Accepted Manuscript

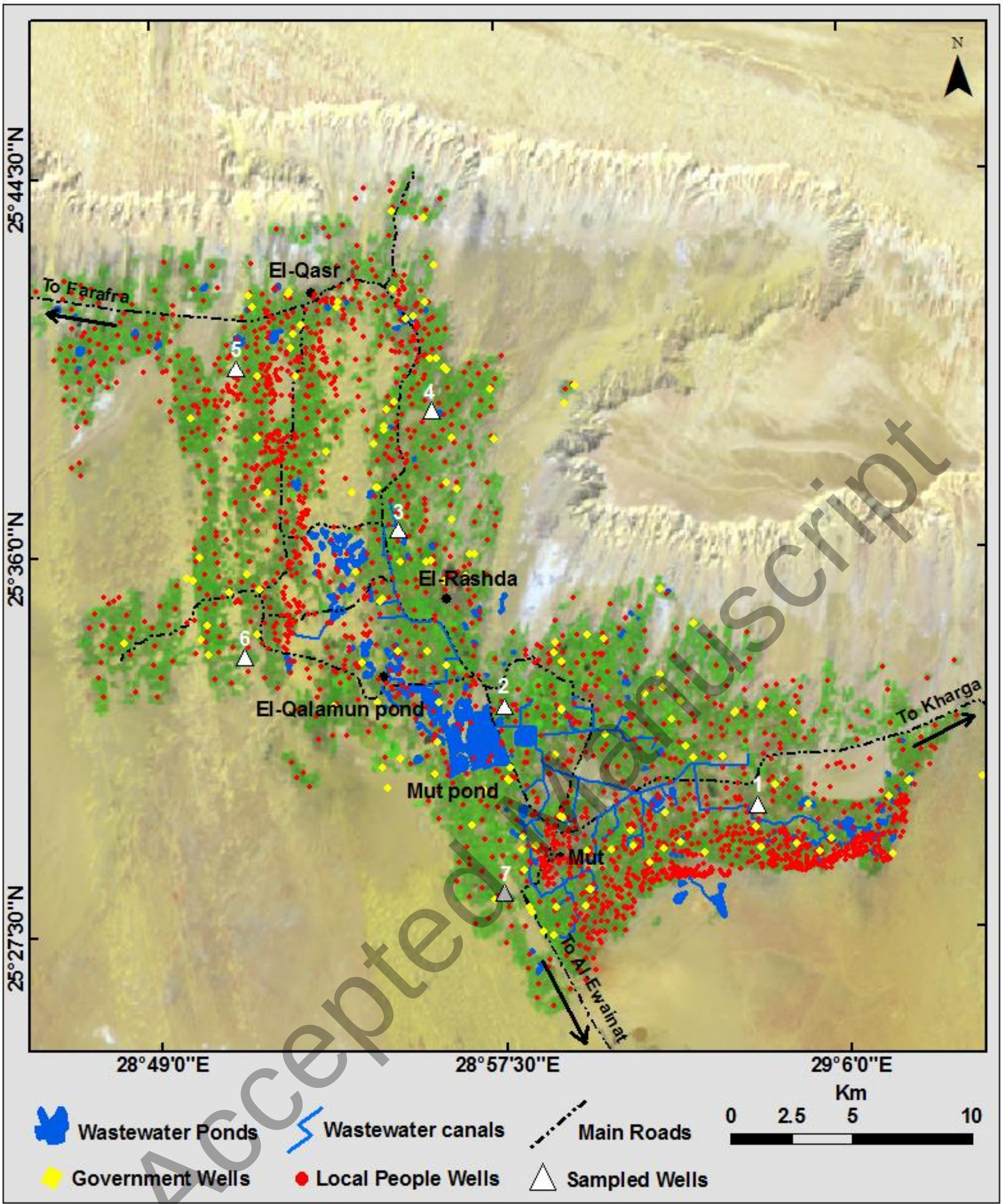


Figure 4. Location map of groundwater wells in the studied area.

Accepted Manuscript

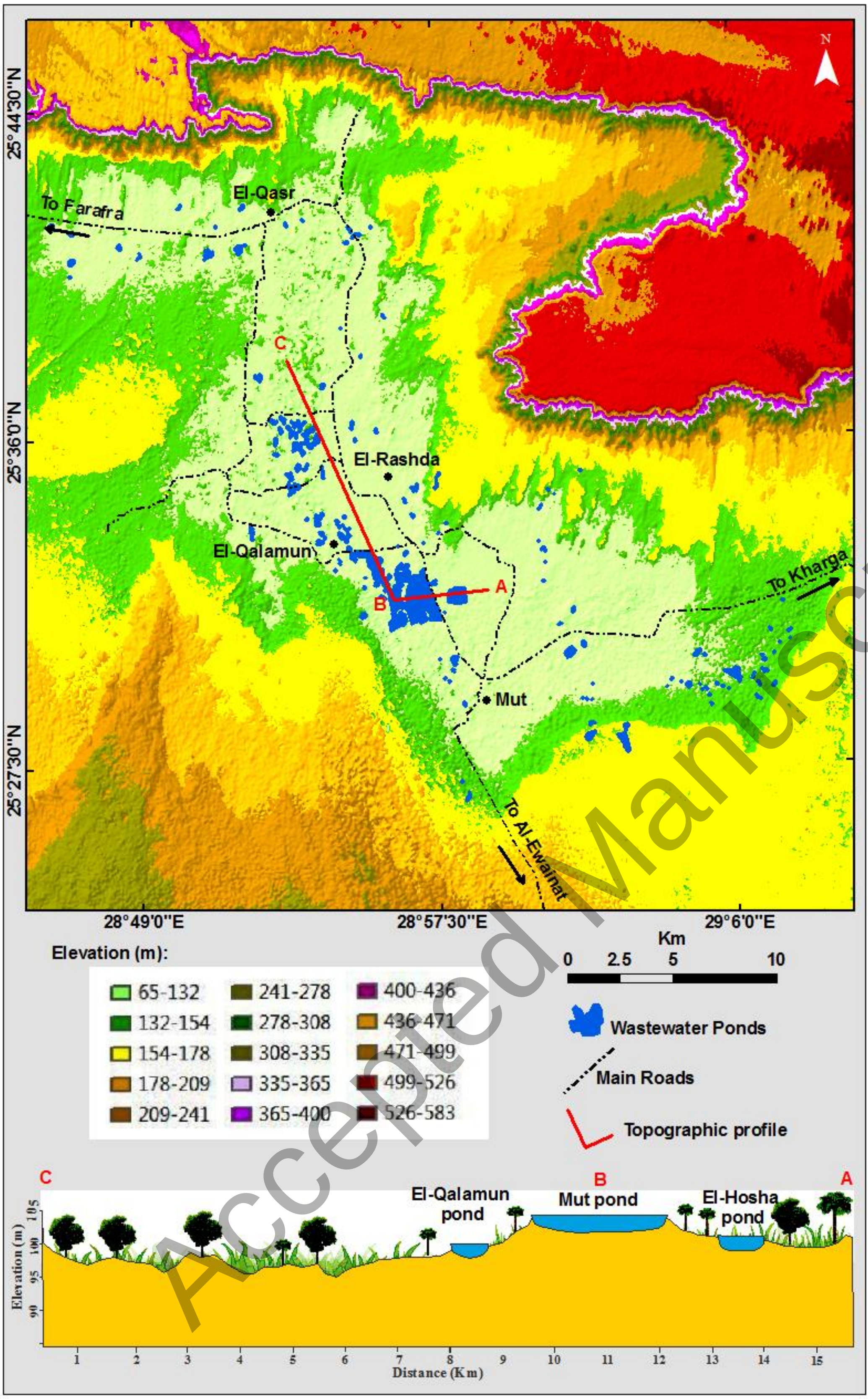
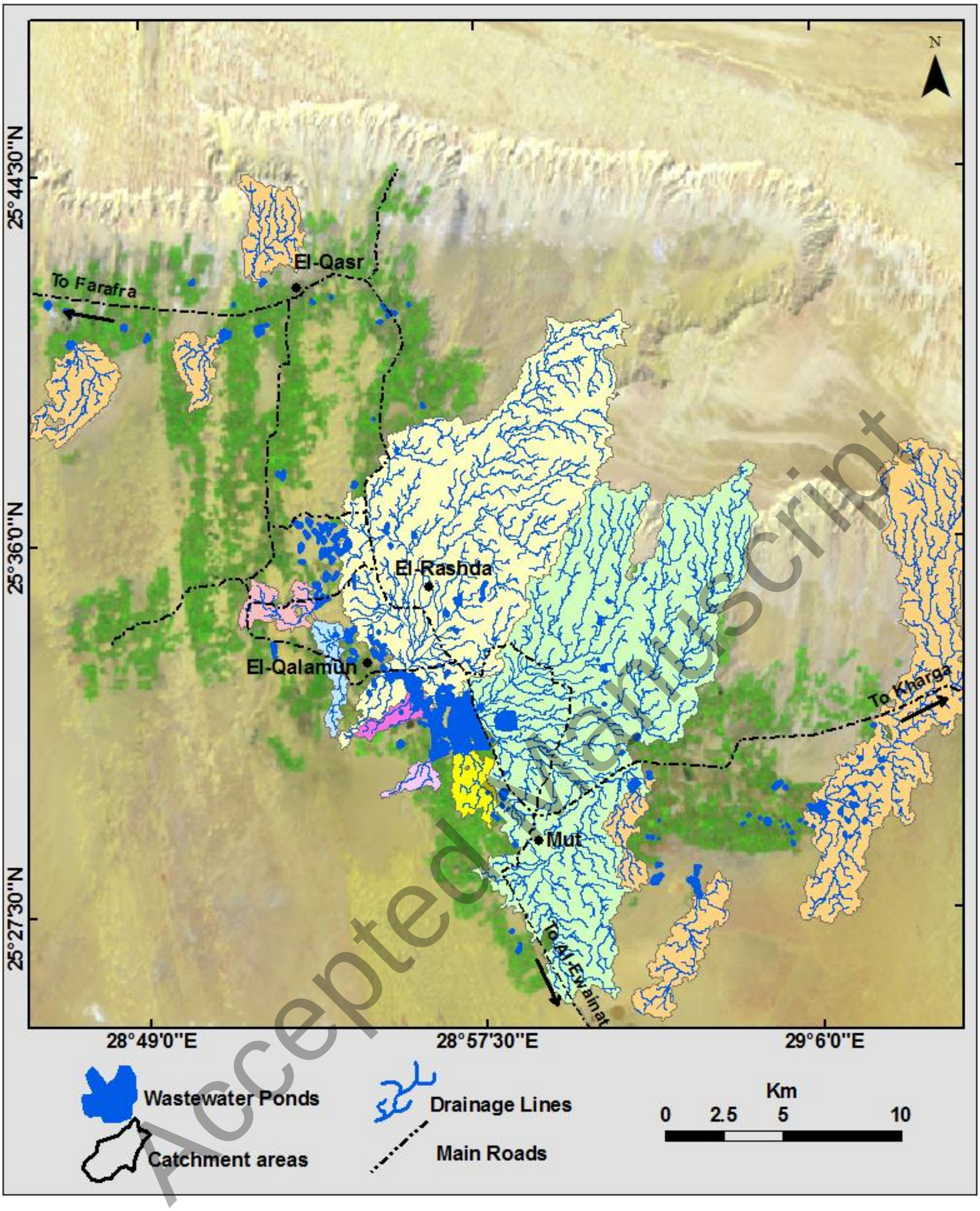


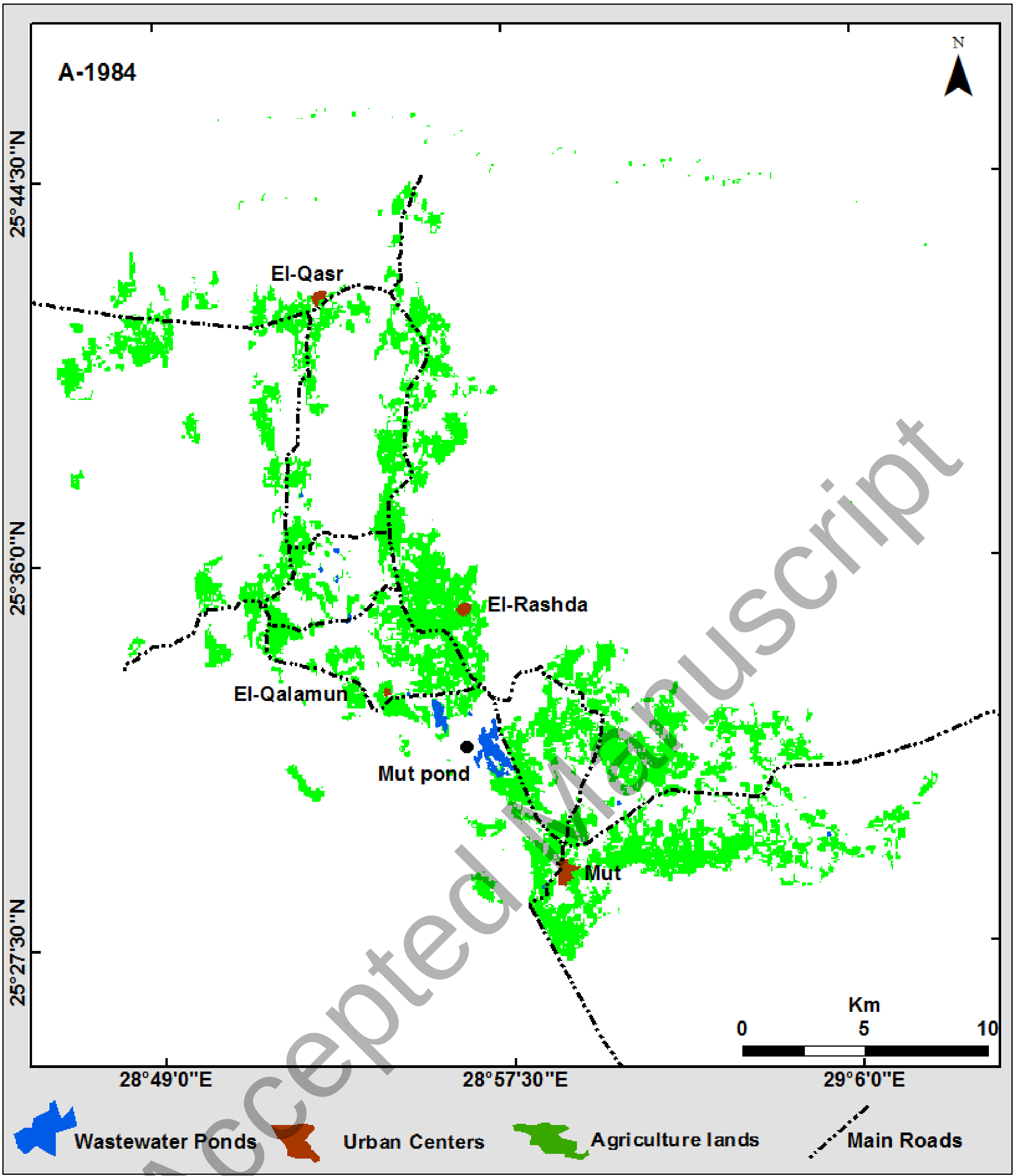
Figure 5. Topographic map with topo profile of the studied area.

Accepted Manuscript

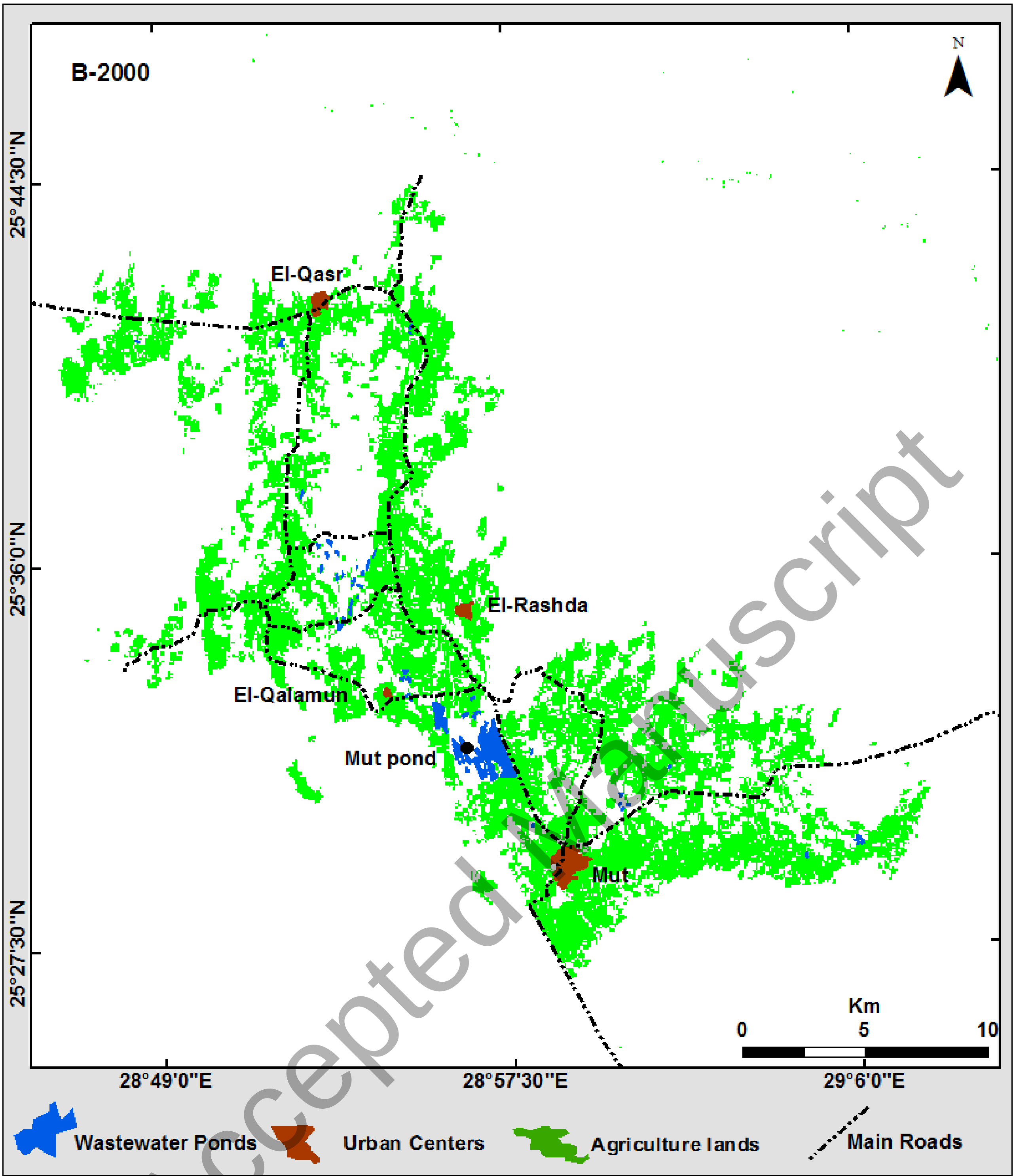


Accepted Manuscript

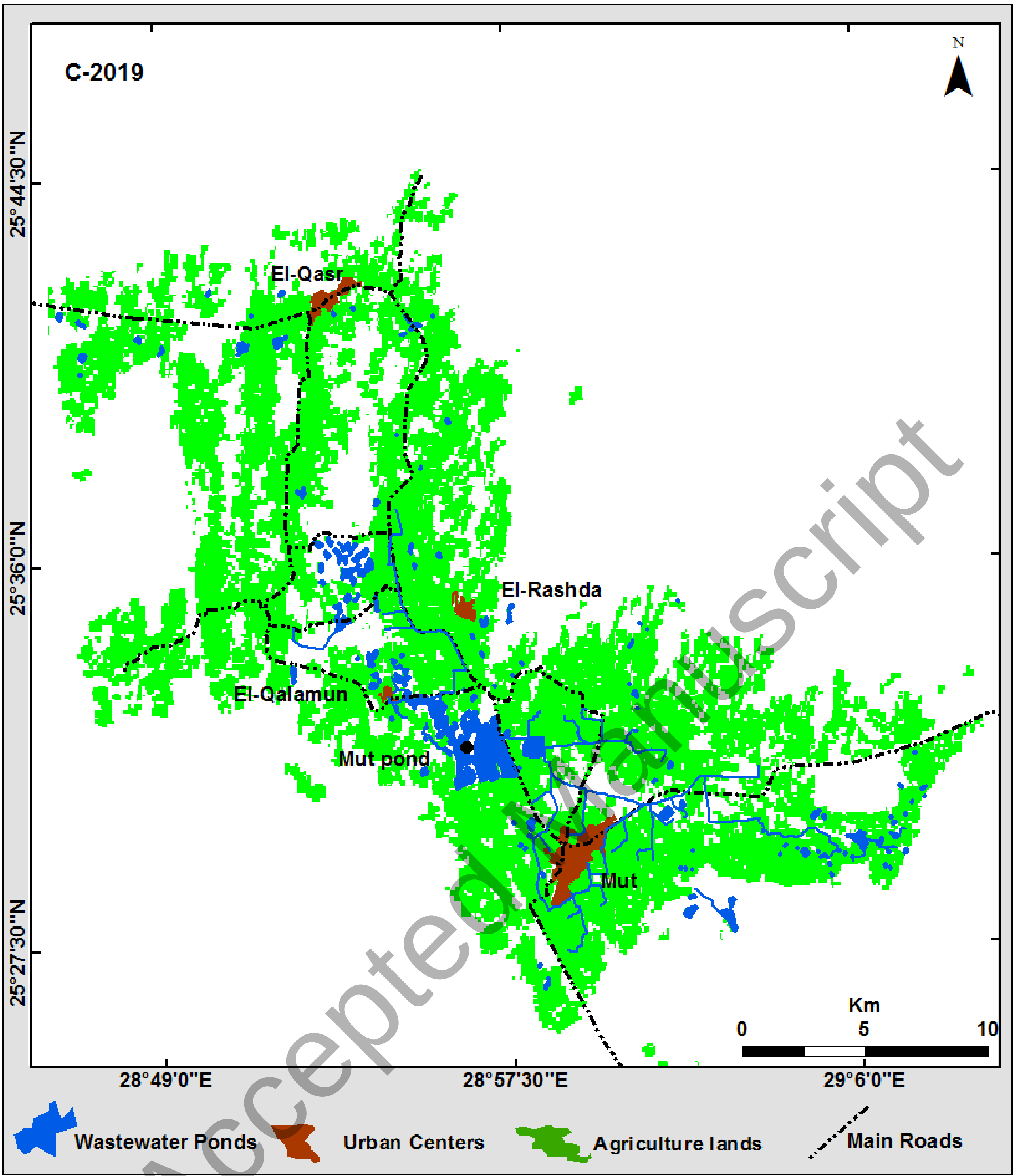
Figure 6. Streams, and catchments inside the studied area.



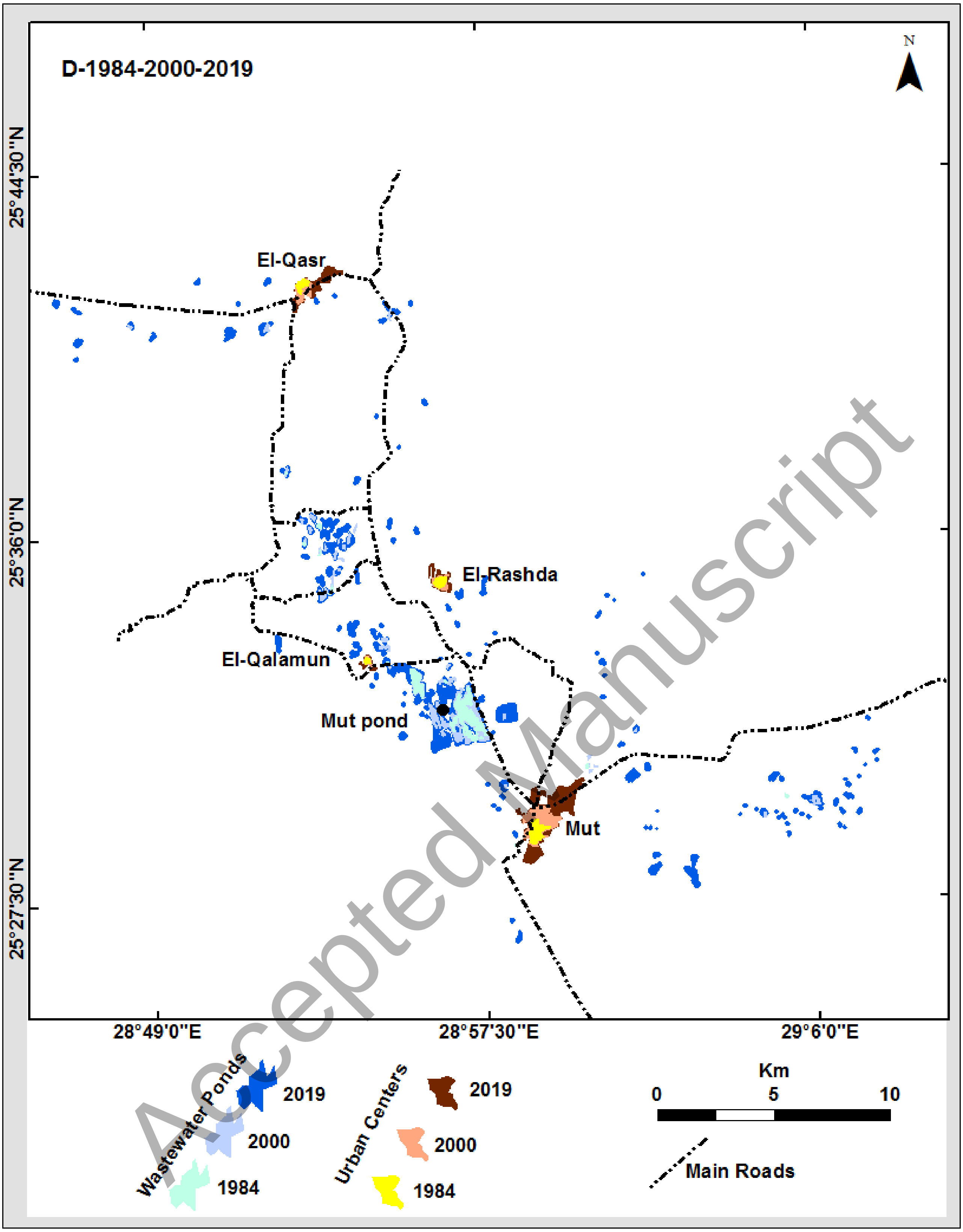
Accepted Manuscript



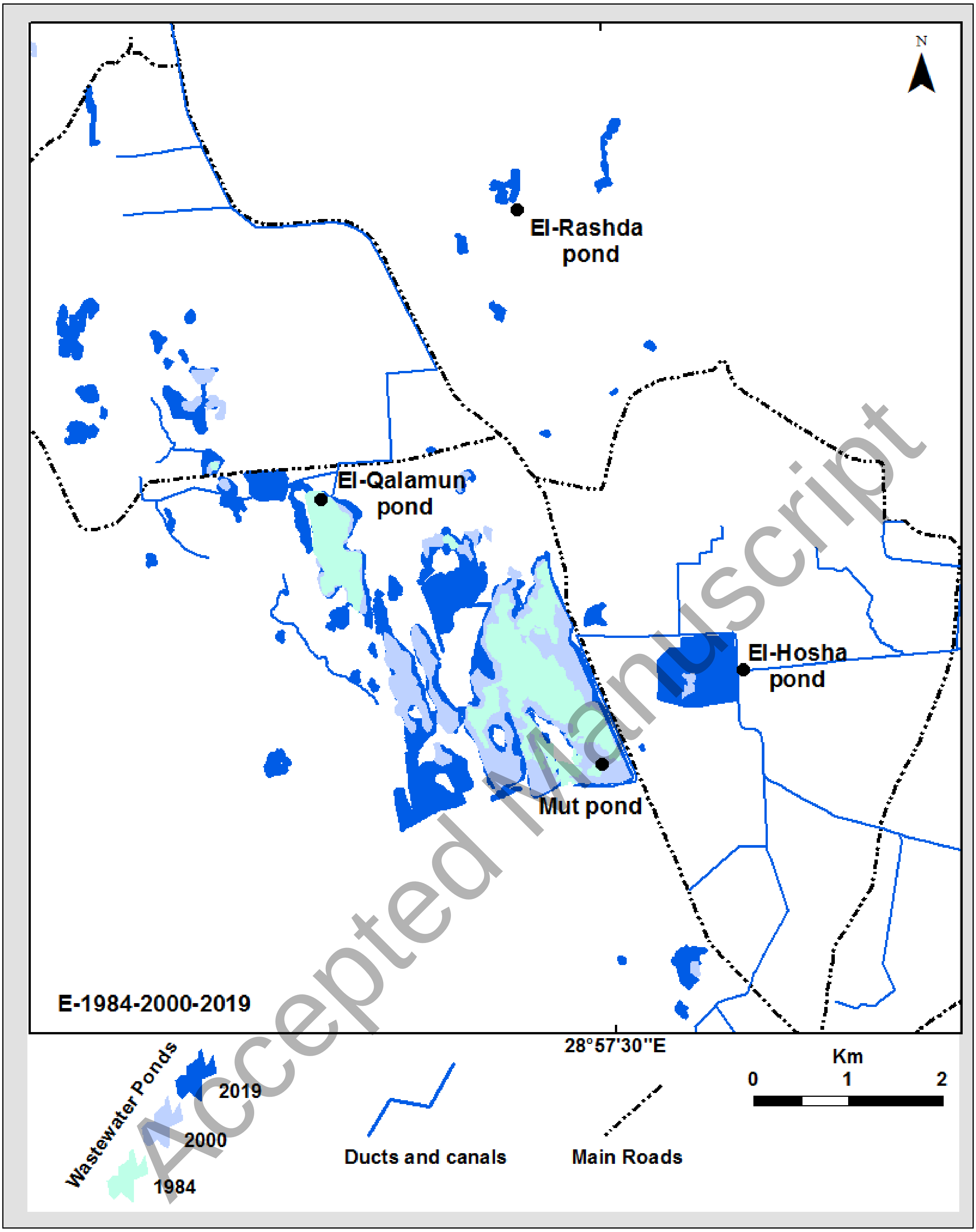
Accepted Manuscript



Accepted Manuscript



Accepted Manuscript



Accepted Manuscript

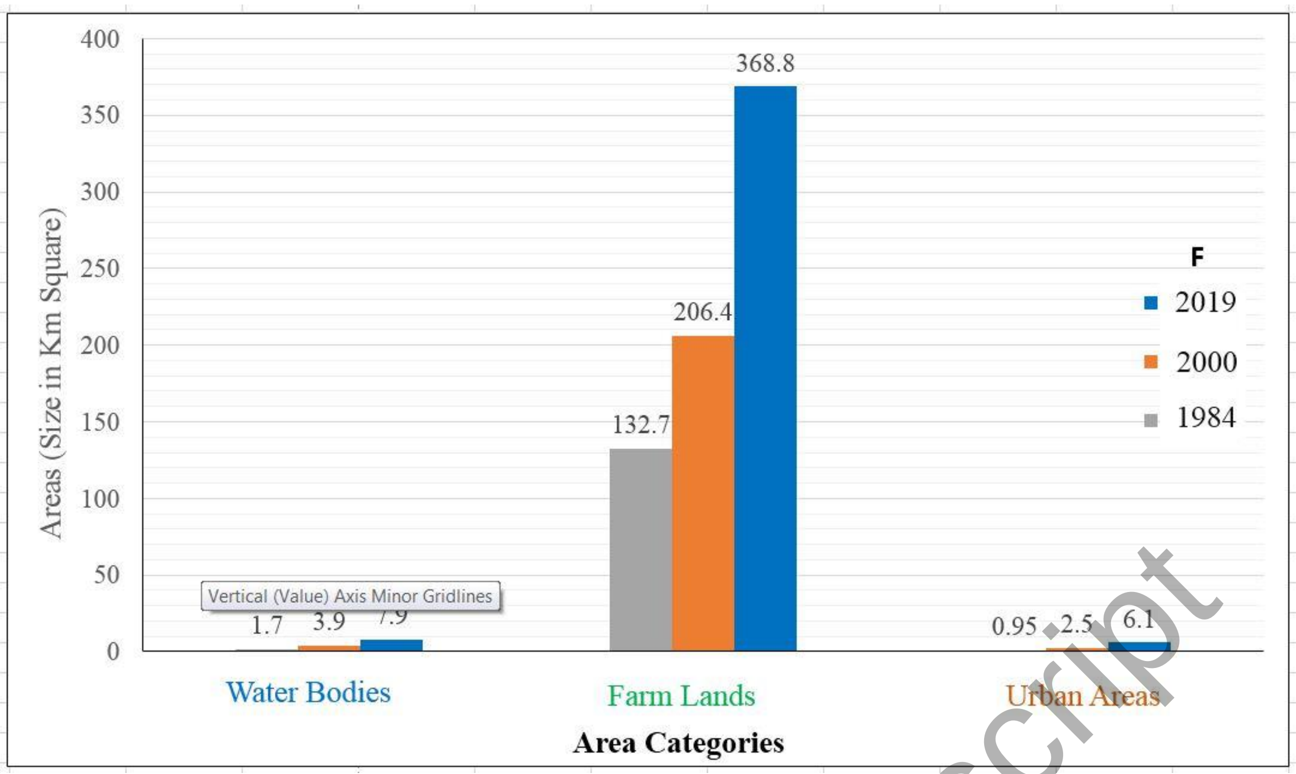
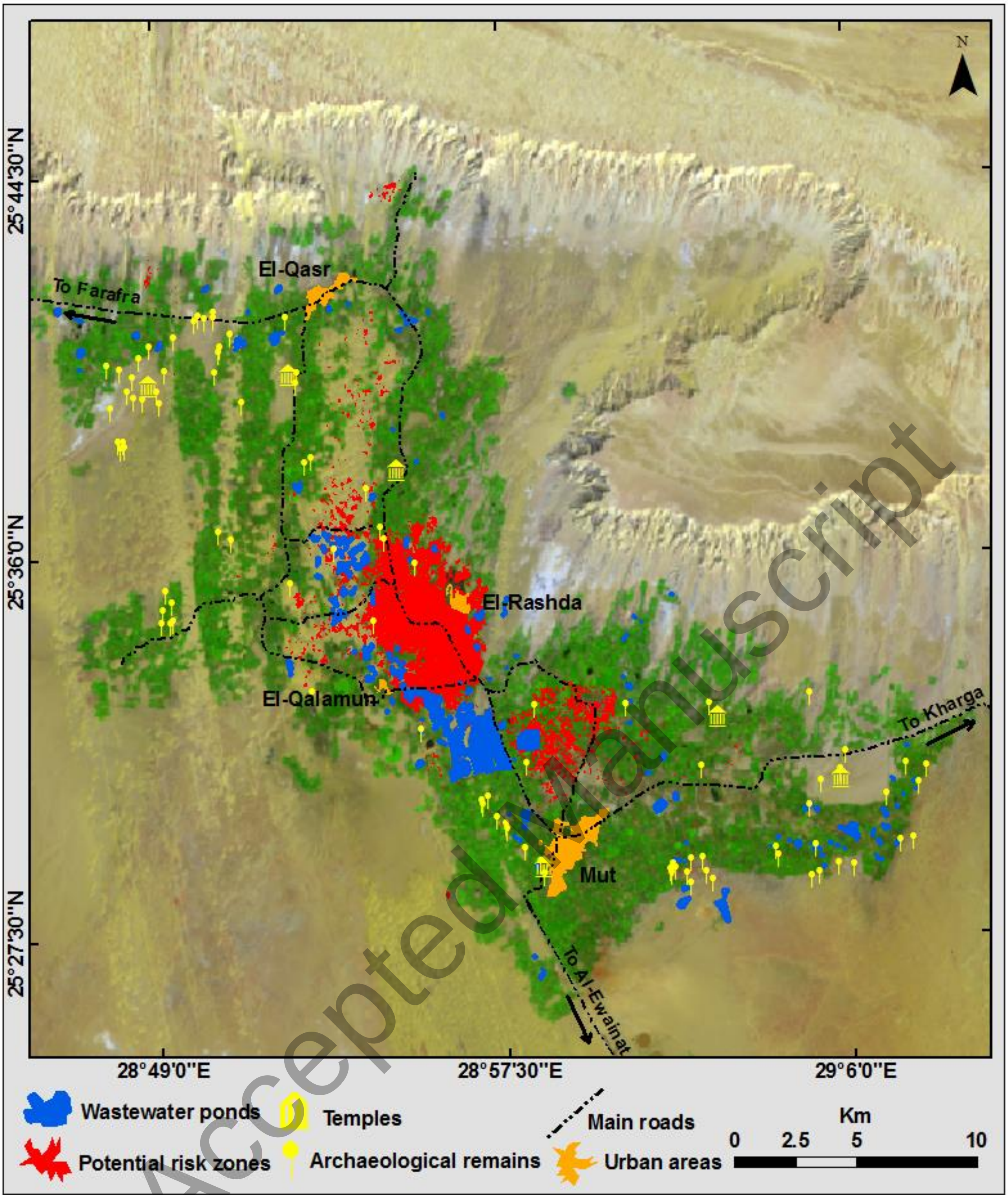


Figure 7. Spatiotemporal variations in 1984, 2000, and 2019 on: (A, B, C) Land use/cover. (D, E) Wastewater bodies, and (F) Histogram of Land use/cover classes in the area.

Accepted Manuscript



Accepted Manuscript

Figure 8. The vulnerability and predictive threat map of the studied area.

Table 1. Analysis of selected water samples represents the study area.

Location / Analysis	Mut Pond	El-Qalamun Pond	Selected Groundwater Wells						
			1	2	3	4	5	6	7
PH	8.58	8.5	6.9	7.4	7.1	7.4	7.5	7.2	6.8
TDS (mg/L)	62080	21000	205	384	192	448	435	445	189
SAR	408	135.23	1.25	2.54	1.12	3.11	2.35	2.85	1.02

Accepted Manuscript

Table 2. Change detection monitored in the study area.

Land use/cover	Area (km^2) (1984)	(%)	Area (km^2) (2000)	(%)	Area (km^2) (2019)	(%)	1984/2019 changes
Agriculture land	132.77	8.1	206.45	12.6	368.81	22.46	+ 236.04 km^2 (14.36%) (increased)
Urban land	0.954	0.07	2.51	0.14	6.1	0.37	+ 5.146 km^2 (0.31%) (increased)
wastewater ponds	1.79	0.12	3.92	0.23	7.91	0.48	+ 6.12 km^2 (0.37%) (increased)
Barren land	1506.39	91.7	1429.02	87.03	1259.08	76.68	-247.31 km^2 (-15.02% (decreased)

Accepted Manuscript