Hydrogeological Investigation and Well Inventory Study in Lar Agricultural Scheme – Sudan

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***Abstract*—Irrigated agricultural LAR scheme in Merowe locality commenced in 2007. Since 2016, the surrounding area has been subjected to a rise in the groundwater table to the land surface, i.e., waterlogging. As a consequence, a lot of houses in the Elregaila region, just adjacent to the main canal, have fallen down. The paper aimed to study this phenomenon in order to propose ample solutions and further mitigation actions. Geophysical and hydrogeological investigations were conducted, and irrigation practice was studied to understand different aspects of the problem. The investigations showed that the main aquifer consists of Nubian Sandstone layers including pebbly sandstone and coarse to medium sandstone intercalated with mudstone. The aquifer area has an annual accumulation (water depth) of 1 to 1.8 m as a result of continual irrigation with approximate storage of 8 million cu m/year and annual abstraction about 1.5 million cu m/year. In accordance with the situations mentioned, it implies that the design of the irrigation conveyance system should be reviewed and weaknesses must be repaired and rehabilitated. Irrigation practice must be changed, as overwatering is a noticed tradition. Integrated irrigation policy using groundwater should be implemented.**

***Index Terms*—Hydrogeological investigation, Lar scheme, Water logging, Well inventory.**

المستخلص **-مشروع اللار الزراعي بمحلية مروي الذي بدأ في العام 2007، تعرضت المناطق المحيطة به لظاهرة ارتفاع منسوب المياه الجوفية في العام 2016 مما ادى الى انهيار العديد من المنازل في المنطقة المتاخمة للمشروع. تهدف هذه الورقة الى دراسة هذه الظاهرة وايجاد حلول عملية والحد من نواتجها. تم استخدام وسائل بحث جيوفيزيائية وهيدروجيولوجية كما تمت دراسة وسائل وطرق الري في المشروع لفهم الجوانب المختلفة للمشكلة. اظهرت نتائج البحث ان الخزان الجوفي بمنطقة الدراسة يتكون من طبقات من حجر الرمل النوبي يشمل احجام خشنة الى متوسطة مختلطة بنوعية من الحجر الطيني. واظهرت الدراسة أنه خلال تلك الفترة ارتفع منسوب الماء الجوفي بمقدار 1 - 1.8 متر. مما أدى الى تراكم 8 مليون متر مكعب في العام مقابل سحب من الخزان الجوفي بمقدار 1.5 متر مكعب في العام. بناءاً على حدوث هذا التراكم لابد من مراجعة تصميم منظومة الري للمشروع واصلاح الخلل بها وإعادة تأهيلها. كما يجب تغيير إدارة نظام الري السطحي بالمشروع. اضافة الى ضرورة استخدام الري التكاملي باستغلال تراكم المياه الجوفية.**

I. Introduction

Continuous water flow into agricultural land may result in groundwater storage building up, which may create a water surplus in the area. Consequently, salts start to accumulate, appearing on the ground surface as deposits. This will lead to the appearance of the waterlogging phenomenon. This represents so high water-table rise close to the ground surface, indicating bad cases where the fields may turn into swamps [1].

Investigation of the waterlogging phenomenon, with respect to the hydrologic formulae, could lead to recognizing the major features perfectly [2]. These features may be mentioned as: Bad drainage of overland run-off increases the rate of percolation and, in turn, raises the water table. Seepage of water from earthen canals also adds a significant quantity of water to the underground aquifer continuously. Furthermore, sometimes subsoil does not permit free flow of subsurface water, which may help the process of raising the water table. In addition, over-irrigation may help considerably in raising the water table. Thus, a good drainage system is very important.

The waterlogging effects in the land may occur in various ways. Occurrence of anaerobic conditions is a major effect in the root zone of the plant. High aeration of the soil motivates bacteriological activities and produces the required nitrates from the nitrogenous compounds present in the soil. It helps crop growth. Excessive moisture content creates anaerobic conditions in the soil. The plant roots do not get the required nourishing food or nutrients. Consequently, crop growth is badly affected [3]. The loving wild plant life grows in the soil were waterlogged increases abundantly. The growth of wild plants totally prevents the growth of useful crops.

Waterlogged lands will not be tilled properly. That is because the soil contains excessive moisture content. The upward rise of water raises the toxic salts in the crop root zone. Excess accumulation of these salts, in turn, makes the soil alkaline. It may prevent crop growth [4]. Extra moisture content decreases the temperature of the soil. At low temperatures, bacteriological activities are retarded, which affects crop growth badly [5].

Previous research is grouped into several patterns such as the mechanism of waterlogging, salinity, plant response, crop yield, and cultural heritage preservation. The combination of poor irrigation water quality, shallow saline groundwater tables, and low-permeability soils always creates a critical effect that severely degrades soil properties and land productivity. The maturity of the crops is a characteristic of waterlogged lands. Due to this shortening of the crop period, the crop yield is reduced considerably. Waterlogging affects the properties of soil and rock layers, hence can also affect building foundations, roads, railways, etc. This requires an urgent strategy to mitigate soil degradation in such critical areas [6], [7], [8].

Utilizing modern techniques and artificial intelligence (AI) technology in irrigation management, farmers can operate with optimal water requirements, thereby reducing water scarcity. Recently, to enable effective water allocation, AI-driven systems are being developed, seeking efficient irrigation management that leads to sustainable food production. Studies show that, for all kinds of farms, smart solutions are significantly increasing crop yield while reducing water consumption on the other hand [9], [10].

As earlier studies provide valuable management and investigation methodologies, this study is unique in assessing the waterlogging phenomenon. It focuses on a study area characterized by a highly raised groundwater table. Old data from pumping tests conducted in the Northern State by the former National Water Corporation and the present Directorate of Groundwater and Wadis have shown that the aquifer in the study area is of low to moderate productivity ranges between 10 and 30 cu m/d. Thus, the question is what the causes of this phenomenon are. It is supposed that it has occurred due to irrigation mismanagement of the Lar agricultural scheme.

The main objectives of this study are to:

1. Assess waterlogging in the Lar scheme, northern Sudan, and its impacts around Merowe town.
2. Investigate the hydrogeological situation and well inventory in the study area
3. Produce a waterlogging hazard map of the study area.

II. Materials And Methods

This study was conducted near Merowe town, in the Northern State of Sudan, about 390 km north of Khartoum. It borders the Nile and is to the south of the site of the Merowe Dam. The study area comprises the Lar Agricultural Scheme; its boundaries are shown between the latitudes north and the longitudes east in Figure 1. Its area covers around 16 sq. km. The Nile, the dominant drainage feature there, flows from northeast to southwest, opposite to the well-known Nile regional flow, which is from the south to the north.

The study area lies within the Nile Sahara basin. The Geological framework consists of Crystalline Precambrian basement rocks, the Cretaceous Nubian sandstone formation, Quaternary to Recent Nile silt and superficial deposits [11], [12]. Two morphological and lithological domains may be distinguished: the domain of the Nubian Sandstone Formation and the domain of Nile alluvium. A geological map of the Northern State was utilized as a reference in the investigation of the geological setting. Detailed geological and hydrogeological information sources were conducted [13], [14],[15],[16],[17].

A digital elevation model (DEM) of the study area was prepared as shown in Figure 2. The figure reveals that the area, in general, is flat, with an elevation of more than 400 m occurring in the southeastern part, where some hills of the Nubian sandstone formation occur. The area occupied by the Nile and its floodplain in the western part of the study area is the lowest, with an elevation of around 215 m. The area has an average elevation of 280 m, with an average gradient of 1: 250 towards the Nile. Khor Abudom represents a local drainage system, as other small water courses generally flow from southeast to northwest.

Fig. 1. Lar Agricultural Scheme – Merowe

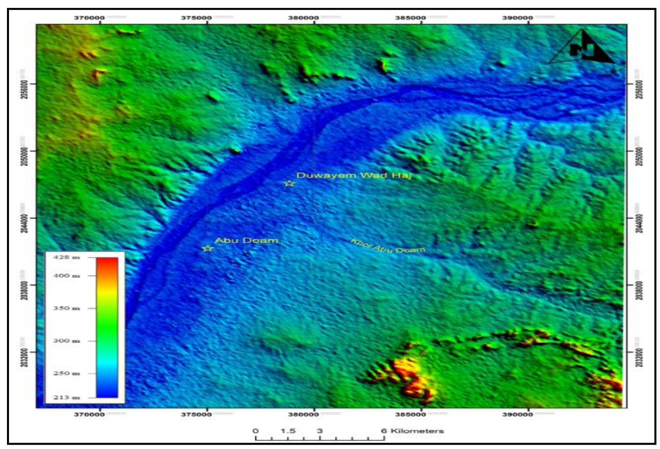

Fig. 2. Digital elevation model (DEM) of the study area

The base map, shown in Figure 3, shows data collection points prepared on a satellite image. The site investigation program carried out included fieldwork and laboratory testing and employed a geo-electrical survey. Drilling boreholes and collecting representative disturbed and undisturbed soil samples. Well inventory was carried out; it included the collection of hydrogeological data from 30 wells and boreholes distributed in the Lar Project and around Merowe town and villages.

Hydrogeological data, including well logs, water level data, pumping test and chemical analyses data, were obtained from governmental directorates and private companies. All data obtained were analyzed using appropriate computer software.

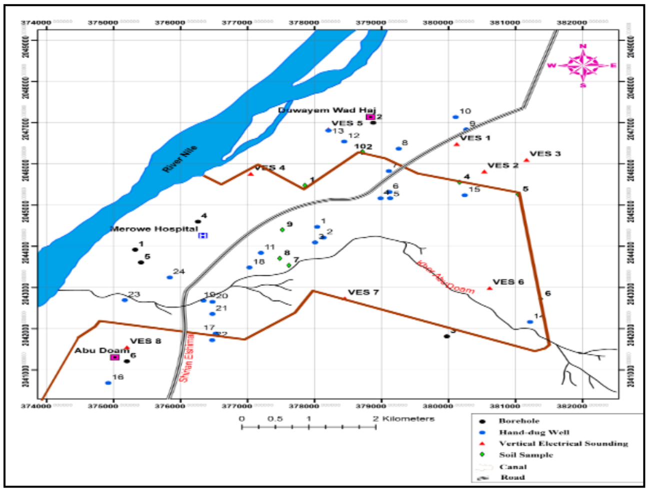

Fig. 3. Base map showing location of data-collection points

III. Results And Discussions

Borehole data and geo-electrical investigations have shown that the groundwater system in the study area is multi-aquifer. The upper hydrostratigraphic unit, a few meters thick, is an aquitard falling within the aeration zone and consists of Quaternary sediments, mainly pebbly sand, sand, and silt. The lower part of this unit is almost wet due to capillary water, which in some locations reaches the land surface and is distinguished from other places by its appearance, sometimes due to salt accumulation.

Geoelectrical investigation and lithological logs have revealed that the aquifer has a thickness range from a few to ten meters, and at the bottom the aquifer is underlain by the basement rocks. The aquifer is unconfined (water-table aquifer). The water-level depth ranges from less than one meter to several meters. Lithological logs revealed that the aquifer is occasionally intercalated with impermeable layers (aquitard) of silt and/or clay. The aquifer is tapped by boreholes and some dug wells, which abstract groundwater by means of simple centrifugal pumps for irrigation.

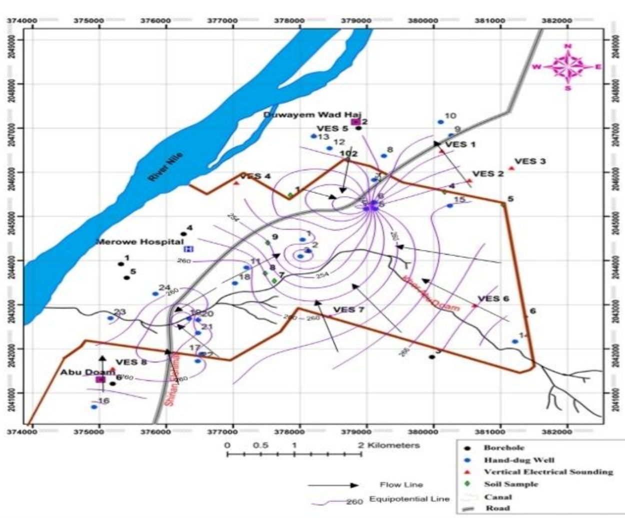

Fig. 4. Water Level Map and Flow Direction

Figure 4 depicts a water level map and the direction of flow. The flow is generally from northeast and southeast towards the west, with areas of low hydraulic head at the center. There is a relationship between the surface flow in the irrigation canal and the groundwater flow, where the flow is from the canal bed towards the area surrounded by the canal. In some places (the northern and southern parts), the flow lines are parallel to the canal or spread out from it. Ultimately, the groundwater discharges naturally into the Nile as base flow or into the low-lying land and khors, e.g., Elrigaila low area in the north and Abudom in the south.

One of the main sources of recharge to the groundwater system in the study area is the seepage from the irrigation system of the Lar scheme. Investigations and water level measurements confirmed that the average water level rose between 12 and 18 m during the period 2008 – 2021, giving an annual rise between 1 m and 1.8 m.

The area of the aquifer considered to be affected by this recharge, which equals the area bounded by the north and east parts of the canal, is about 8.4 million sq m. Thus, the annual recharge is estimated as 8.4 million cu m at a minimum to 12.6 million cu m. Groundwater is sometimes used for irrigation, particularly in summer and when the scheme pumps stop due to maintenance or a sudden failure. Well inventory revealed that about 30 wells are working for irrigation purposes at an average rate of 250 cu m/d per well, for a period of 6 months during the year, so this will give a total discharge of about 1.5 million cu m/year. From estimated input and output, the area has a water surplus. Estimated aquifer transmissivity of 25 sq m/d, considered as an intermediate value [18]. Thus, the reason for the water table rise during the last decade, and the occurrence of waterlogging, is due to overwatering.

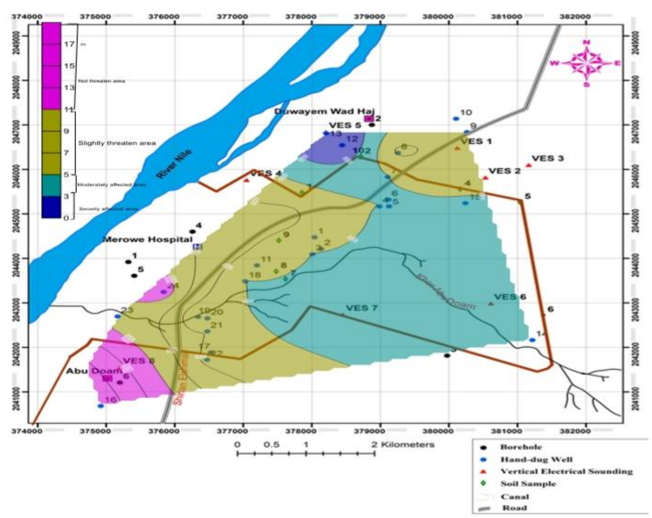

Fig. 5. Waterlogging in the Study Area (hazard map).

Waterlogging has appeared in the study area, including areas in the irrigation command as well as other adjacent areas. The areas in the irrigation command get waterlogged due to a rise in the water table as a direct consequence of inadequate drainage and affect the adjacent areas. Other areas that get waterlogged are topographically low and represent old or present water courses. Figure 5 shows a hazard map representing the spread of waterlogging over the study area.

IV. Conclusions

Seepage of irrigation water in the Lar scheme, which appeared in the residential area of Elregaila village, either from irrigation canals or the cultivated area, was investigated. The study concludes that,

1. Water level rise, with annual accumulation estimated as 1 to 1.8 m, ultimately caused the waterlogging phenomenon.
2. Waterlogging hazard map of the study area
3. The thickness of the upper aquifer system is relatively limited; hence, groundwater discharges into the adjacent lowland areas and depressions.
4. The waterlogging problem of the Lar agricultural scheme has to be minimized by redesigning and lining the canal system to minimize loss of water due to seepage.
5. Efficient management is required to reduce percolation from the field and channels.
6. Installation of a lift irrigation system and implementation of a drainage system are required.

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