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A Study on Effective Use of Surface Runoff for Irrigation in Djibouti

- Watershed Analysis using GIS and Trial on Runoff Parameters Estimation -

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Abstract: Djibouti is located in the Northeastern part of Africa and most of the land is covered by desert area. To secure irrigation water in Djibouti, we evaluated how to use surface runoff water effectively. We selected the Kourtimalei reservoir watershed as the target area of this study. Using satellite data (Aster GDEM) we derived the reservoir's watershed area employing GIS, and supplemented detail data through a field survey.

To start, we observed the weather data in this area, and at the same time we also began to collect water level data from the Kourtimalei reservoir. According to our observations, the water level dropped 42 mm/day in August, 2012. Moreover, to investigate runoff parameters, we set up rain gauges and pressure type water gauges at three points within this watershed area for delineation of precipitation and temporal surface water distribution. From these results, we proceeded to develop a method for an effective use of surface runoff caused by occasional rainfall in this arid land.

Key Words: GIS, Reservoir, Runoff parameters, Surface runoff, Watershed analysis

1. Introduction

Djibouti is located in the Northeastern part of Africa, with most of the land covered by desert with annual rainfall of ca. 100-200 mm. There is only small amount of crops cultivation (wadi agriculture), and hence the self-sufficient ratio of food is only 3%. Though there is little rainfall, the rainfall intensity is high and therefore runoff water sometimes causes damage to the facilities in Djibouti.

On the other hand, when large amounts of rain fall in a closed watershed such as the BARA desert, rainfall water accumulates and ponding areas stay for several months. Without utilization, however, ponded water is lost by evaporation and infiltration to ground in a few months later.

To secure irrigation water in Djibouti, we studied how to use the surface runoff water effectively. We propose a consecutive water reservoirs system to preserve effective water. To apply this system, we tried to search the optimal reservoir position using GIS, and tried to get run-off parameters of our target watershed in Djibouti.

In order to carry out a specific study, we selected a part of the Grand Bara desert watershed located in the southern part of Djibouti. We selected the Kourtimalei reservoir watershed as the target area of this study. The Kourtimalei reservoir is located near the Grand BARA desert in the southern part of Djibouti (N 11° 18', E 42° 40', **Fig. 1**). The reservoir was constructed by the Ministry of Agriculture, Fishery, and Livestock in charge of Marine Resources, Djibouti (**Fig. 2**). We constructed an experimental farm adjacent to this reservoir and implemented a cultivation trial using storage water. It was therefore important for us to analyze the water catchment area. As we could not get a detailed elevation map of Djibouti, we used satellite data (Aster GDEM) and we derived the reservoir's watershed area by using GIS (Spatial Analyst of the ArcGIS expansion software) and supplemented detail data with a field survey. We have been trying to clarify the runoff characteristics of rainwater in this watershed. From these

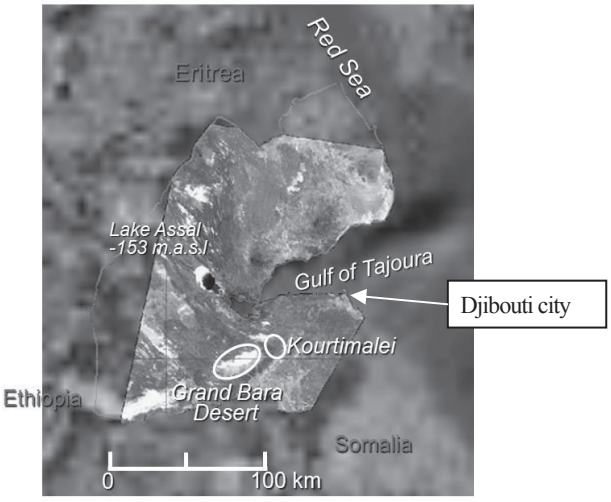

Fig. 1. Location of target area in Djibouti.

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Fig. 2. The conditions of Kourtimalei reservoir. Dried up condition (4 Mar. 2013); Filled up condition (1 Aug. 2013).

Table 1. Rainfall characteristics in Djibouti (Djibouti airport).

year	annual rainfall (mm)	maxmum monthly rainfall (mm)	occurred month	maxmum daily rainfall (mm)
2000	143.8	48.0	May	34.9
2001	48.2	48.2	August	42.1
2002	200.2	48.2	January	36.4
2003	90.7	29.4	December	14.6
2004	207.6	108.1	April	92.9
2005	96.2	22.2	May	17.9
2006	182.5	58.5	August	58.2
2007	33.8	15.6	July	14.3
2008	66.5	55.5	November	46.3
2009	33.5	24.6	January	19.6
2010	58.3	44.7	August	27
2011	88.8	38.5	October	37.6

results, we are attempting to develop a method for an effective use of rainfall. Specifically, we make the selection of suitable sites for ponds from the topographical information by watershed analysis using GIS. Because rainfall is assumed to have a large variation in each region, we installed the water level gauge and rain gauge to retrieve the runoff characteristics in Kourtimalei region.

2. Materials and Methods

Our overall goal is to find a way to effectively use the large amounts of surface runoff water, resulting from temporary heavy rains, for irrigation. The characteristic of the rainfall in Djibouti is that there are few rain events and little rainfall (30 - 210 mm/yr) for the past 10 years (**Table 1**). In addition, daily precipitation often exceeds a half of the annual rainfall.

We plan to apply a consecutive reservoir system (Kitanaka *et al*, 2008) with the aim to efficiently use the reservoir water. For this reason, it is necessary to understand the distribution and characteristics of depression areas in the basin, and to identify suitable pond locations. On this basis, we tried to clarify the rainfall runoff characteristics of the target basin and identify the basin parameters for reservoir storage and use of this water for irrigation.

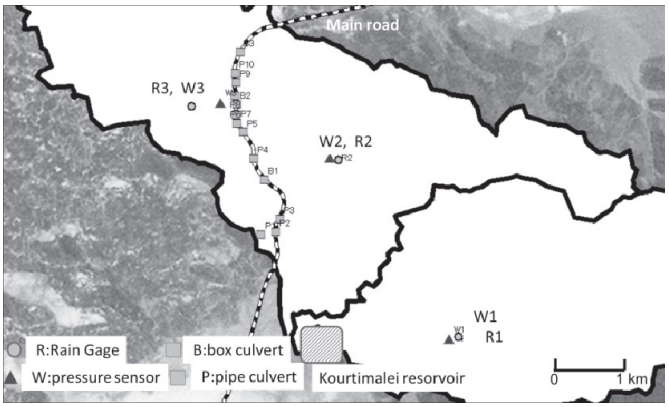

Fig. 3. Installation position of rain-gage and water-level pressure sensor and the location of road crossing concrete culvert.

The Grand Bara desert watershed is a closed basin and rainfall runoff gathers in the Grand Bara desert. However, the region is in a state of non-flooded condition most of the year due to minimal rainfall. It is only when there is a large amount of rain that water flows from the surrounding hills towards the Grand Bara desert, and this whole area becomes flooded temporarily with shallow water depth, with this water basin sometimes remaining flooded for several months. The Kourtimalei reservoir is a facility of damming runoff water flowing into the Grand Bara desert by embankment. The reservoir does not hold water very deep, but it is very wide in range, since the location is in a very flat area near the Grand Bara Desert. Because of this status, it is not efficient enough in terms of water storage, but availability of stored water is greater than letting it flow into the Grand Bara Desert.

As the digital map for Djibouti is not complete, to identify the watershed we used global elevation data observed by satellites using Aster GDEM (resolution 30 m). We estimated the watershed boundary using GIS software. We used Spatial Analyst which is the extension software of ArcGIS10.1 (ESRI Inc.)

We installed weather observation equipment (temperature, relative humidity, solar radiation, wind speed and direction, rainfall) in the observed experimental field adjacent to the embankment and started recording measurements in August 2012 (**Fig. 3**). A pressure gauge (HOBO, U-20) was installed in the reservoir to observe the pond water level. In addition, we installed rain gauge (HOBO, RG3-M) and water level sensors (HOBO, U20) in three spots (cf. Fig. 3) within the basin on June 2013, and tried to identify the rainfall runoff characteristics (**Fig. 4**).

Regarding the setting of the water level sensors, these were installed inside perforated steel pipes (3 inch diameter), to protect them from debris flowing with rain outflows. We fixed the base of the pipes with concrete (Figs. 4 and **5**).

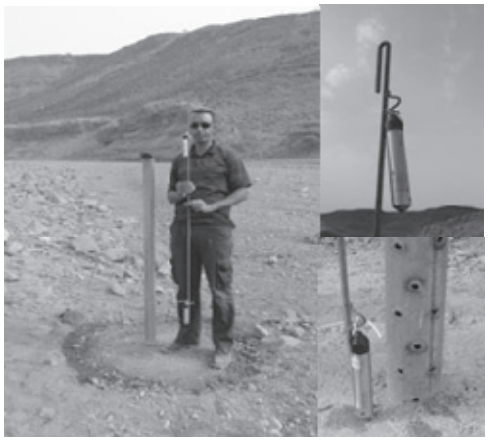

Fig. 4. Water- level pressure sensor installed in perforated steel pipe for protection in the watershed of Kourtimalei reservoir.

Fig. 5. Rain-gage and water-stage recorder installed in wire-mesh and perforated steel pipe for protection in the watershed of the Kourtimalei reservoir.

3. Results and Discussion

3.1. Analysis of Kourtimalei reservoir basin using GIS

Based on information from an existing map and the results of basin analysis using GIS under natural conditions, the catchment area in the reservoir installation point is estimated to be about 18 km^2. The reservoir embankment, however, is long enough to catch runoff water from the west adjacent basin. Therefore, subsequent investigation is needed to clearly delineate the areas contributing to the watershed reservoir. In this watershed area, if the Kourtimalei embankment did not exist, rainfall runoff flows directly toward the Grand Bara Desert under natural conditions. The total watershed area was calculated to be about 40 km^2 (**Fig. 6**). In addition, we could confirm 13 large and small culverts (3 box culverts and 10 pipe culverts) crossing a main road located upstream on the right bank of the Kourtimalei reservoir (Figs. 3 and **7**).

3.2. Situation of flooding in Kourtimalei reservoir

We carried out simple surveying around the reservoir and the outskirts, and made a cross section of a bank body and the reservoir. As a result, we characterized the relationship between reservoir water level and total reservoir storage (**Fig. 8**).

We observed large amounts of rainfall during August 2012,

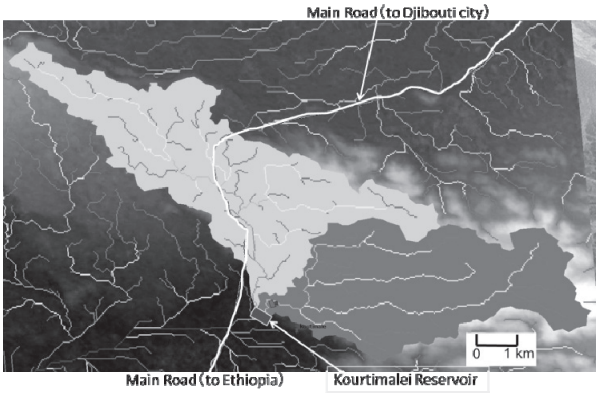

Fig. 6. Watershed of Kourtimalei reservoir. The natural watershed is the area in darker blue, whereas the area in light blue is the added watershed after the constructed watershed.

Fig. 7. Concrete culvert crossing the main road. Box culvert on left and pipe culvert on right.

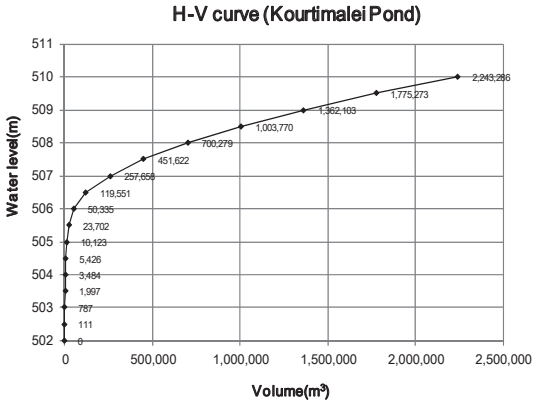

Fig. 8. Relationship between water level and water storage volume on Kourtimalei reservoir.

March and August 2013. At these times the Kourtimalei reservoir was filled with runoff water.

The amount of water in Kourtimalei reservoir was estimated roughly at 550,000 m^3 on August 2012. Under the conditions of withdrawing small amounts of irrigation water for experimental fields, storage water remained in the reservoir for about four months without additional rainfall in 2012.

According to our observations, the water level in the reservoir dropped 42 mm/day in August, 2012, while the amount of decrease was 35 mm/day during September-October. The area of the experimental fields is about 2 hectares with some vegetables, NERICA rice, trees for windbreak and other cultivated crops. The water of the reservoir was pumped up

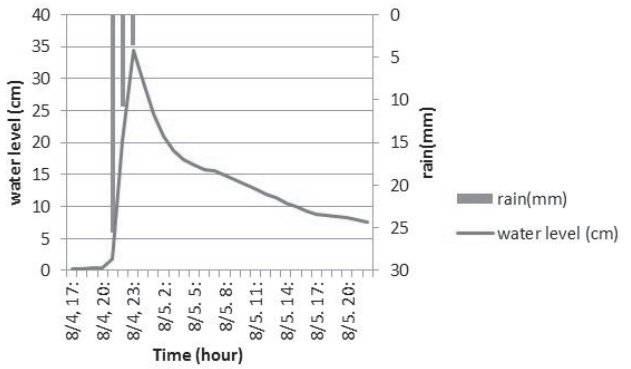

Fig. 9. Rainfall at Kourtimalei and runoff water level at the W3 point.

and used for basin irrigation.

By observing the water level changes, we clarified the characteristics of the water volume changes. We tried to reflect this outcome including estimation of the amount of water used for irrigation.

3.3. Rainfall runoff characteristics

The characteristics of precipitation in southern Djibouti include sparse rainfall, high rainfall intensity and large regional variations (Takahashi *et al*., 1994). These concur with the typical rainfall characteristics of drylands. Therefore, in order to know exactly the runoff characteristics of the Kourtimalei basin, rainfall observations in the field are required.

To investigate runoff parameters, we set up rain gauges and pressure type water gauges at three points within the Kourtimalei reservoir watershed area (Fig. 4) in June, 2013. These allowed for delineation of precipitation and temporal surface water distribution.

In August 2013, a relatively heavy rainfall was observed around the reservoir, and it was filled with runoff water. This precipitation event alone was equivalent to about half of the annual average rainfall for the region. This information is useful to clarify the degree of non-uniform distribution of rainfall and its localization.

On the midnight of August 4, a heavy rainfall event occurred at the measurement point W3, which recorded 40 mm in 3 hours. The peak rainfall intensity was 25 mm/hour (**Fig. 9**). Wadi water level at this same point suddenly rose, reaching a maximum of 35 cm in about two hours after the rain started. After cessation of rainfall, the water level was reduced rapidly in half in about 3 hours. Thereafter, a drawdown occurred slowly. We suppose the slow drawdown was due to clogging of the perforated holes of the steel pipe with sediment and debris during the storm event.

4. Recommendations

According to the rainfall data at the Kourtimalei reservoir basin, runoff water begins to flow shortly after the onset of rainfall. In the future we will collect and accumulate more rainfall data and runoff amounts, and estimate an outflow rate of the basin. Based on the watershed analysis using satellite data and GIS, we will try to find a suitable reservoir setting site and the reservoir capacity of this basin. From these results, we are planning on getting an effective use of runoff water using a consecutive irrigation reservoir system.

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