Mayo UP Disaster Risk Reduction

ZDD2BFB22F

Field assessment and survey of the Angola district of Mayo camp

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2 ABSTRACT

Italian

Nell’ambito del contratto “Mayo UP Disaster Risk Reduction – ZDD2BFB22F” dal 29.02 al 05.03 un Team di tecnici di Fondazione CIMA ha effettuato sopralluogo e rilievo dell’area di interesse all’interno del distretto di Mayo-Angola (Khartoum). L’area è particolarmente vulnerabile sia ai periodici allagamenti che la interessano sia per le condizioni sanitarie, sia per le difficoltà di accesso. Obiettivo finale dell’intervento di Fondazione CIMA è sviluppare un Ponding Risk Assessment (PRA) volto a individuare le aree prioritarie a più elevato rischio per allagamento e proporre un sistema di smaltimento delle acque superficiali.

Durante la missione sono state individuate le possibili linee di intervento per mitigare, in emergenza e in pianificazione, gli allagamenti causati dalle precipitazioni tipiche della stagione umida ed è stata delineata una progettazione di massima delle opere di drenaggio delle acque superficiali.

Il Team era composto da:

- Luca Ferraris, Ingegnere Civile Idraulico, docente di Costruzioni Idrauliche e Presidente di Fondazione CIMA;
- Simone Gabellani, Ingegnere per l’Ambiente e il Territorio, esperto di Idrologia e Idraulica, coordinatore del dipartimento di Idrologia e Idraulica di Fondazione CIMA;
- Alessandro Masoero, Ingegnere per l’Ambiente e il Territorio, esperto di GIS, Idrologia e Idraulica, ricercatore e Project Manager presso Fondazione CIMA;
- Umberto Morra di Cella, Dottore Forestale, pilota di aeromobile a pilotaggio remoto (APR o drone) ed esperto in telerilevamento con particolare riferimento all’impiego di tecniche di rilievo in contesti emergenziali,
- Laura Poletti, Ingegnere per l’Ambiente e il Territorio, esperta di Idrologia, ricercatrice presso Fondazione CIMA.

Le principali attività condotte nel corso della missione sono state:

(01/03) Ricognizione preliminare dell’area di Mayo-Angola volta a verificare lo stato dei luoghi e le limitazioni operative connesse all’esecuzione del rilievo, valutare le caratteristiche plano-altimetriche dell’area, stabilire un primo contatto con istituzioni ed enti/organismi presenti in loco e acquisire tutti gli elementi utili alla pianificazione delle missioni di acquisizione tramite APR (Aeromobile a Pilotaggio Remoto). Al rientro in sede AICS Khartoum si è dettagliato il piano di volo e acquisizione per il rilievo topografico, valutando le zone di maggior interesse anche alla luce delle aree inondate rilevate da Satellite (Sentinel, ESA) durante l’evento di agosto 2019.

(02/03) Realizzazione del rilievo topografico di dettaglio tramite acquisizioni di immagini da drone (senseFly ebee X RTK equipaggiato con fotocamera RGB SODA 3D 20 Mpx), e installazione temporanea di una antenna GNSS. L’area mappata ha una superficie di circa 3 km^2 e si estende attorno all’ospedale pediatrico di Emergency. Alla realizzazione del rilievo hanno partecipato come osservatori i tecnici della Sudan Survey Authority (SSA).

(03/03) Restituzione fotogrammetrica del rilievo topografico con produzione (Agisoft Metashape 1.5.3) di un modello digitale della superficie (DSM) e di un ortomosaico ad altissima risoluzione (rispettivamente 13 cm/px e 3,5 cm/px). L'impiego di un drone dotato di tecnologia RTK e l'installazione temporanea di una antenna GNSS hanno consentito l'ottenimento di accuratezze di posizionamento elevate anche in assenza di punti di controllo a terra. Le attività di restituzione sono state occasione per la formazione di alcuni tecnici della Sudan Survey Authority.

Nella stessa giornata si è iniziato lo studio idrologico volto a stabilire frequenza e intensità delle piogge intense che causano l'allagamento dell'area di interesse, sulla base dei dati globali e locali disponibili in letteratura. I valori massimi di pioggia cumulata per evento e per stagione delle piogge sono stati usati come informazioni di ingresso per definire il dimensionamento delle soluzioni tecniche volte a ridurre il rischio di allagamento nell'area oggetto di studio. Al fine di aumentare la conoscenza delle condizioni meteorologiche locali, una stazione meteorologica è stata installata sul tetto della sede AICS di Khartoum. La stazione, caratterizzata da una tecnologia a codice aperto, permette il monitoraggio in tempo reale della quantità di pioggia, della temperatura e dell'umidità relativa.

(04/03) Analisi della topografia e individuazione della rete di drenaggio superficiale dell'area rilevata (circa 3 km^2) al fine di definire lo stato di fatto dei luoghi. I dati del rilievo topografico insieme alle stime di pioggia sono stati usati come valori di ingresso per una simulazione idraulica di dettaglio, che ha permesso la delineazione delle aree soggette ad allagamento dove risultano prioritarie opere di contenimento e smaltimento delle acque superficiali. In accordo con AICS è stata identificata come area oggetto di un primo intervento di mitigazione del rischio di allagamento l'area ad alta densità abitativa di Mayo-Angola che ha una estensione di circa 0.13 km^2 attorno all'ospedale pediatrico di Emergency. In tale area sono stati classificate le tipologie abitative in funzione della loro copertura (case in terra, tettoie in juta, tettoie in lamiera, coperture in plastica). Il conteggio delle strutture abitative ha permesso una stima della popolazione residente e della densità abitativa nell'area di Mayo-Angola. Ipotizzando nuclei familiari composti da 5 a 7 individui si stimano circa 15'000 persone concentrate in un'area ridotta di circa 0.13 km^2.

Sull'area prioritaria di Mayo-Angola sono state individuate alcune possibili soluzioni tecniche per ridurre il rischio di allagamento in emergenza (prima della stagione delle piogge 2020) quali: (i) la pulizia e riprofilatura di alcuni canali esistenti non più funzionali allo smaltimento delle acque di pioggia, (ii) la realizzazione di nuovi canali comprensivi di culvert per l'attraversamento stradale, (iii) il pre-dimensionamento di serbatoi di raccolta delle acque di pioggia dai tetti che potrebbero essere idonei.

A livello di pianificazione, è stato dimensionato e progettato uno schema di massima per una rete di drenaggio che permetta lo smaltimento delle acque superficiali dell'area nord di Mayo.

In tale giorno inoltre due esperti CIMA hanno realizzato una sessione di formazione del personale del Sudan Survey Authority (base di Omdurman – Khartoum) relativo all'impiego di droni ad ala fissa per il rilievo topografico (pianificazione, realizzazione di riprese, pre-processamento);

(05/03) Incontro con la viceministro per gli Affari Esteri e la Cooperazione Internazionale Emanuela Del Re svoltosi presso la sede AICS Khartoum. Durante la riunione è stata presentata l'attività svolta durante la missione, i primi risultati e le ipotesi di intervento per mitigare, in emergenza e in pianificazione, il rischio di inondazione. Dopo la presentazione si è svolta una visita direttamente nel distretto di Mayo dove la viceministro ha potuto vedere, insieme ad altri progetti e interventi, le condizioni attuali dell'area di Mayo-Angola.

Con l'obiettivo di definire e coordinare le attività progettuali, si è tenuta una riunione con il coordinatore regionale e con il rappresentante paese di COOPI, ONG coinvolta direttamente nel progetto Mayo-Up e impegnata nell'area di Mayo-Angola. Sono state individuate sinergie, quali gli interventi di raccolta acque, tra il lavoro tecnico di Fondazione CIMA e il lavoro sul campo di COOPI, da portare avanti sotto il coordinamento di AICS Khartoum.

Short abstract in English

CIMA Foundation carried out with the Italian Civil Protection Department an assistance action in Khartoum, Sudan, within the framework of the "Mayo Up" Project, funded by the Italian Agency for Development Cooperation (AICS). The intervention aimed at assessing ponding-prone areas in the Mayo refugee and IDP camp, defining possible surface water disposal solutions and providing assistance and advice on disaster risk management to relevant staff of local DRMA.

A detailed field survey, using remotely piloted aircraft (drone) and GNSS measurements, has been carried out by CIMA topographic experts, to define current surface water drainage conditions and create a high-resolution Digital Surface Model (DSM). The high detail DSM obtained has been used as primary input for subsequent desk study activities aimed at highlighting most vulnerable areas during rainy season severe events, where to target mitigation interventions.

Furthermore, the drone survey allowed an accurate estimation, through imagery detection of housing units, of people currently living in Mayo Angola, the most densely populated district of the camp.

3 INTRODUCTION

On the 21.02.2020 CIMA Foundation and AICS stipulated the contract "Mayo UP Disaster Risk Reduction - ZDD2BFB22F". The aims of the contract are to enhance the risk knowledge through a site-specific flood risk assessment and decrease population vulnerability to disaster events defining possible solutions to drain surface water in the district of Mayo-Angola (Khartoum, Sudan)

With the aim of assessing ponding-prone areas, defining possible surface water disposal solutions and providing assistance and advice on disaster risk management, the activities are composed of three main phases: (i) field survey, (ii) desk analysis and design, (iii) result delivery and technical assistance. The tasks of the activities are:

- T1: perform a detailed field survey (mission 1), using Unmanned Aerial Systems (UAS) and GNSS measurements, in the Area of Interest (AOI) of Mayo-Angola camp;
- T2: develop a tailored Ponding Risk Assessment (PRA) for the AOI, considering the direct precipitation driven inundations that affect the area;
- T3: define a surface rain water drainage system for the AOI, according to topography and specific needs derived from the field survey;
- T4: provide capacity building on civil protection/early warning to relevant staff of local disaster risk management institutions, organising a tailored training (mission 2) and ensuring remote support throughout the intervention.

Between the 29 of February and 5 of March a Team of hydraulic engineers and remote sensing experts conducted a field survey with Unmanned Aerial Systems (drones), in the district of Mayo-Angola (Khartoum, Sudan) with the aim to evaluate current state of the places and create a high-resolution Digital Surface Model (DSM). The DSM is the first ingredient to develop a tailored Ponding Risk Assessment (PRA) for the AOI, considering the inundations due to direct rain water that affect the area.

This report illustrates the results of the field survey (T1), the elaboration of the DSM and of the products that define the current natural drainage of water, Ponding Risk Assessment (T2) and proposes solutions for first interventions and recommendations for planning (T3).

To deliver these tasks, specific inputs on AOI topography, rainfall conditions and vulnerable area needs are required. These data have been collected and processed by the Team of Experts during the field survey (mission 1) and desk analysis. The primary outputs of the activities are: i) a high detail DSM of Mayo-Angola camp; ii) a site-specific study on pluvial risk; iii) a proposal of possible surface rain water drainage solution during severe rain events; iv) tailored reports on technical work and capacity building activities performed.

4 T1: DETAILED FIELD SURVEY USING DRONE AND GNSS MEASUREMENTS

4.1 Survey Flights

On the 2nd of March the field survey was realized by Digital Aerial Photogrammetry (DAP) based on images collected by Unmanned Aerial Systems (UAS). The main goal of the acquisition is to produce a very high-resolution orthomosaic and very high-resolution Digital Surface Model (DSM) of Area of Interest (Figure 1).
The activity was authorized by the Disaster Displacement and Resettlement (DDR) Commission of Sudan for a limited circular area with a half kilometre of radius centred on the Emergency paediatric hospital. A specific VHF frequency was assigned for the radio communication between crew components and other involved persons. All operations were supervised by two delegates of Sudan Survey Authority (SAA) and every change applied to the broad program was discussed and approved by themselves and Mayo-Angola Municipality representative.

Due to the size of the surveyed area and the difficulty of moving around the area for materializing and measuring Ground Control Points (GCPs), a fixed-wing provided with RTK option was used. In this operational configuration, the on-board multi-frequency GNSS receiver can determine the camera position at shooting time with cm-level accuracy thanks to differential corrections sent by a GNSS master station (Geomax Z35 Pro).

The UAS images were collected using a senseFly eBee X RTK (see Table 1) equipped with a senseFly S.O.D.A. 3D mapping camera, a professional drone photogrammetry camera changing orientation during flight to capture three images (2 oblique, 1 nadir) each time for a much wider field of view (see Table 2) and for a best vertical elements’ reconstruction.

Figure 1: Area of Interest (AOI) located in Mayo-Angola district of Khartoum.

Table 1: senseFly eBee X RTK specifications.

Wingspan	116 cm
Weight (MTOM)	1.3 kg
Motor	Electric, brushless
Take off / Landing	Hand launch / Linear landing
Cruise speed	40 km/h (11-14 m/s)
Maximum flight time (regular battery)	50 minutes
Absolute X, Y, Z accuracy (RTK/PPK activated)	1.5 cm (0.6 in) + 2 ppm

The ground station (laptop equipped with radio modem) for mission planning and UAV control was installed in the Emergency hospital garden in order to respect the procedures provided by the “Operations manual” (safety and security items). The GNSS base station was placed on the high curb (concrete) near to the Emergency container, on an unknown position (the point is not part of a national topographic network), stable in terms of x, y and z and identified in the future (see Figure 2). Five people were involved in the UAV survey: a pilot, an observer (positioned on the Emergency water reservoir, see Figure 3) and three support people.

Table 2: senseFly S.O.D.A. 3D photogrammetry camera specifications.

Sensor	1”
RGB lens	F/2.8-11, 10.6 mm (35 mm equivalent: 29 mm)
RGB resolution	20 Mpix - 5,472 x 3,648 px (3:2)
RGB shutter	Global Shutter 1/30 – 1/2000s
RGB FOV	Total FOV: 154°, 64° optical, 90° mechanical

Figure 2: Ground station and GNSS RTK base station (15° 28’ 09.1574” lat N, 32° 32’ 51.7217” lon E, elevation – ellipsoid 393.180 m – base height: 0.095 m).

The missions were planned using senseFly Emotion 3.10.0 software (build 207). According to the goal of the survey, the features on the terrain (pseudo-urban texture, height of buildings, spacing of the elements, …) and payload characteristics, three blocks (B1, B2 and B3) were designed with horizontal mapping, 3.50 cm/px resolution, 149 m elevation above take-off, 80% lateral overlap and 70% longitudinal overlap. Because the partially open area acquired with the Block 4 the lateral overlap was reduced to 75%.

Table 3: Survey flights data summary

Block (name)	Time TO (hh:mm)	Time LAND (hh:mm)	Duration (min)	Strips (n)	Distance (km)	Images (n)	Images with RTK-fixed (n)
B1	8:56	9:43	47	23	35.8	669	669
B2	10:35	11:12	37	30	29.0	431	431
B3	11:26	11:57	31	15	24.2	300	300
B4	12:16	12:46	30	22	22.7	311	267
			145		**111.7**	**1.712**	**1.667**

Four flights were executed between 8:56 A.M. and 12:46 A.M.; during the activities the wind speed reached 6-7 m/s with South direction. The air temperature was 37 °C at 11:00 A.M. and the air relative humidity 10-15%. The main parameters of each flight are shown in Table 3.

Figure 3: Location of observer during the operation.

Figure 4: Flight paths (B1: magenta, B2: yellow, B3: cyan, B4: green)

4.2 Photogrammetric Data Processing and Outputs

Photogrammetric Data Processing was executed with the commercial package Agisoft Metashape 1.5.3 build 8469. Block orientation was performed with SfM algorithms in an arbitrary reference frame. A Helmert transformation was computed from the arbitrary reference to the object reference system (EPSG: 4326 – WGS 84), based on the camera centre positions, loaded directly from the image geotags (corrected by RTK datastream coming from GNSS base station). A global optimization stage was then executed that minimizes the sum of the reprojection error and of the camera station coordinate residuals; camera parameters were estimated by self-calibration.

From each photogrammetric block a specific dense cloud was carried out and the relative DSM and orthomosaic was computed, respectively with interpolation and without hole filling. The DSM resolution is 13 cm/px while the orthomosaic resolution is 3,5 cm/px.

The main information obtained from aerial survey is consistent between the four flights: the comparison of elevation (ellipsoid) of the same point (pixel) derived from two independent dataset (blocks) shows a high accuracy of DSM and the differences is always lower than the pixel size. Therefore, the DSM of the whole area, derived from the single block DSM merging, can be used to detect hydraulic features and the drainage system.

Figure 5: Digital Surface Model of Mayo-Angola area derived from UAV survey (resolution 13 cm/px)

Figure 6: Orthomosaic (true colour) of Mayo-Angola area derived from UAV survey (resolution 3.5 cm/px)

5 T2: PONDING RISK ASSESSMENT (PRA) FOR THE AOI

Due to availability of resources, time and temporal framework the Area of Interest (AOI) selected for the primary emergency interventions, as agreed with AICS, is the area that surrounds the Emergency paediatric hospital (Figure 7).

Figure 7: Selected area of Interest (AOI): Mayo Angola

5.1 Precipitation analysis

The following data have been collected and analysed to estimate the climatology of the area:

- Raingauge SIEREM (Système d'Informations Environnementales sur les Ressources en Eau et leur Modélisation). Monthly data available for raingauges in the surrounding area of Khartoum covering different time windows starting from 1906 to 1991.

- Satellite data CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data). Monthly data from 1981 to 2018 with grid resolution of 0.05°.
- Satellite data MSWEP (Multi-Source Weighted-Ensemble Precipitation). Three- hourly data with 0.1° spatial resolution, from 1979 to 2017.
- Raingauge dataset from Sudan Meteorological Authority, extracted from Mahmoud et al. 2014. Maximum daily rainfall per year from 1980 to 2011.

The first two sources of information regarding the rainfall statistics in the Khartoum area have been used in order to assess climatology. Based on the raingauge data the seasonal distribution of the rainfall can be assessed. The analysis of datasets points outs that rainfall is mainly concentrated in the summer season, from June to September, with a mean value of 130 mm.

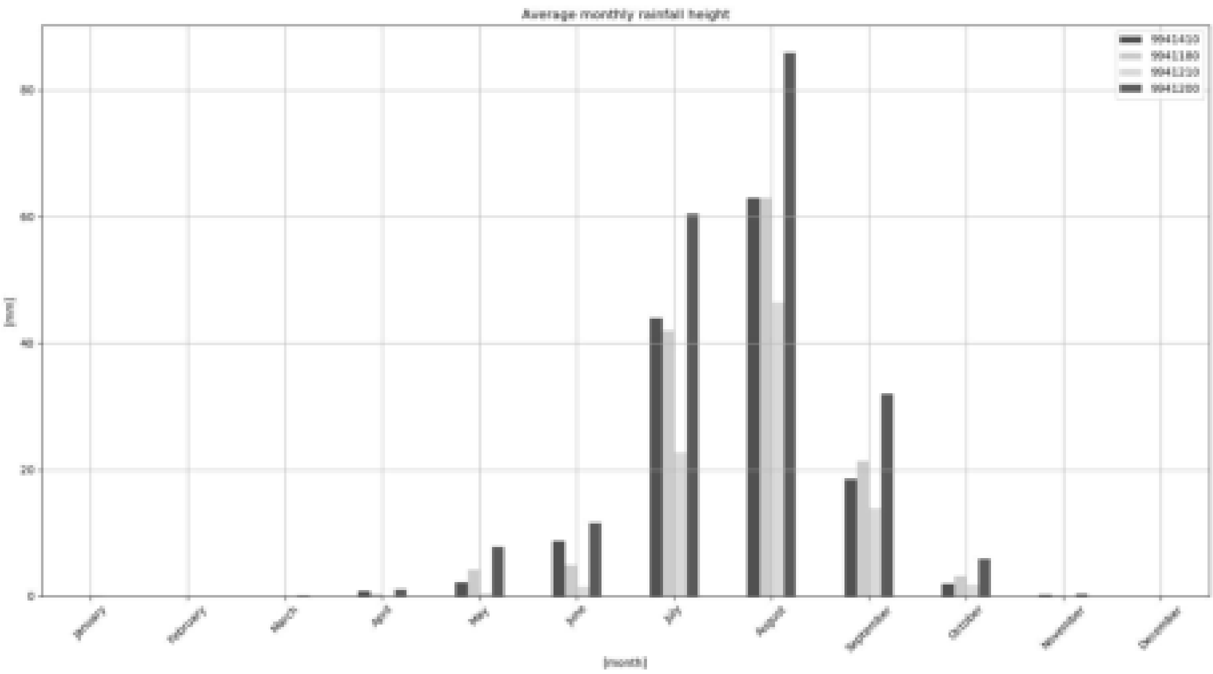

Figure 8: Monthly average data from raingauges of SIEREM dataset

The Rainfall Depth Duration Frequency curves have been estimated using MSWEP rainfall data accumulated over 3, 6, 12, 24 hours.

From the 3-hours rainfall data the maximum for every duration (3-6-12-24 hours) for every year has been calculated. With these data mean, standard deviation and variation coefficient of the maximum time series has been calculated. These values are necessary to estimate the Rainfall

Depth Duration Frequency curves, that represent the variability of the rainfall height with the duration for different return periods (here 5-10-50-100-200-500 years).

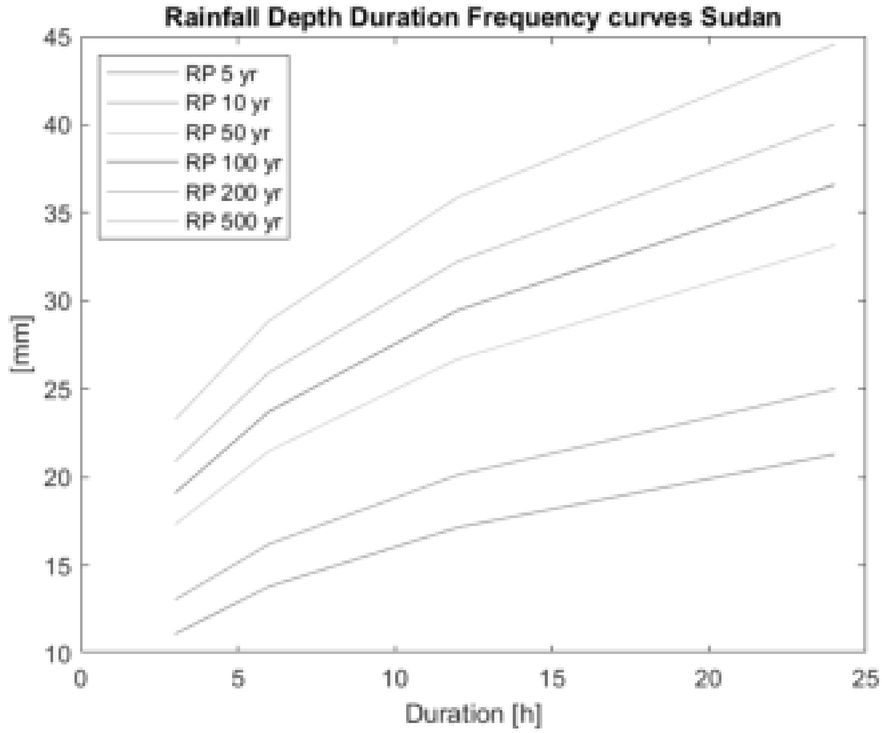

Figure 9: Rainfall Depth Duration Frequency curves for Sudan (derived from MSWEP)

Since these curves are based on rainfall values calculated as average of satellite pixels containing the area of interest a correction using ground rainfall data (extrapolated by Mahmoud et al. 2014) has been applied. In fact, from a comparison performed between the MSWEP yearly maximum data accumulated over 24 hours and the maximum daily data per year of the Sudan Meteorological Authority (SMA) on the overlapping years of the two dataset (2000-2011) it is possible to observe a substantial underestimation of the rainfall for the MSWEP data.

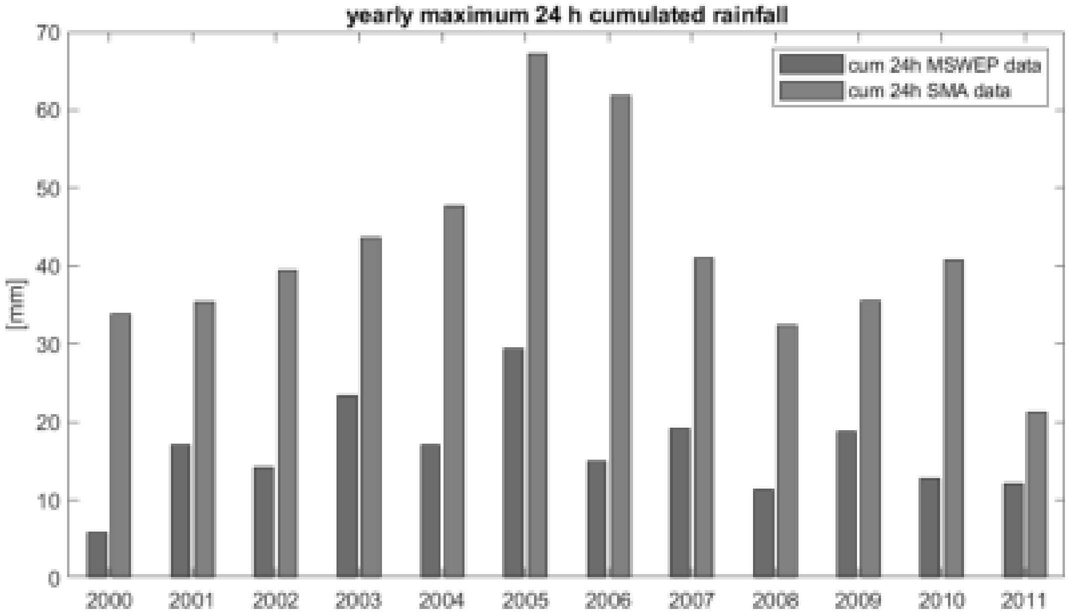

Figure 10: Daily accumulated value from MSWEP and SMA

Starting from these data the quantile mapping technique has been applied to modify the GEV of the MSWEP data in order to fit the SMA data. Doing so the corrected Rainfall Depth Duration (RDD) curves have been obtained using the rescaled value of rainfall.

Among those RDD curves the values of the curve related to the 1-in-10 years return period are used for the estimation of the project rainfall for the dimensioning of the drainage system. The maximum cumulative rainfall values per event and per rainy season were used as input to dimension the technical solutions aimed at reducing the risk of ponding in the area under study.

In order to increase knowledge of local weather conditions, a weather station was installed on the roof of the AICS headquarters in Khartoum. The station, characterised by an Open-Hardware technology, allows real-time monitoring of rainfall, temperature and relative humidity conditions.

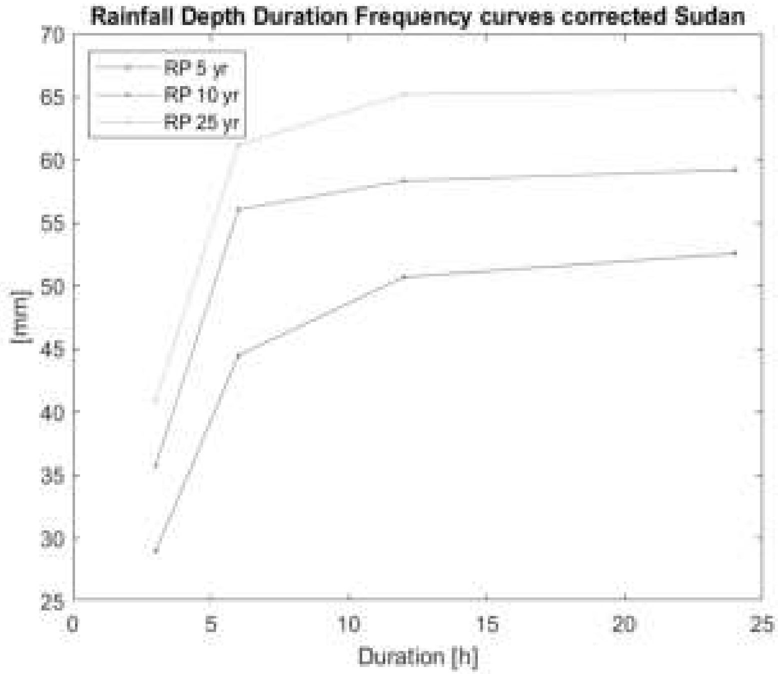

Figure 11: Corrected Rainfall Depth Duration Frequency curves for Sudan

Figure 12: Installation of the weather station on the roof of AICS office in Khartoum.

5.2 DSM analysis

In order to identify drainage directions and ponding-prone areas under current conditions, the DSM has been elaborated using GRASS GIS software. Considering the DSM image as a geo-referenced matrix where every cell reports its own surface elevation value, drainage directions provide the aspect of each cell, that is the direction surface water will flow in a given cell according to pixel-by-pixel slope.

Having identified drainage conditions on the area covered by the topographical survey, contributing basins (i.e. areas that collect water towards the same outlet point) can be identified. According to the GIS analyses performed, surface water is currently flowing towards the North (Figure 11) and Mayo Angola is receiving a non-negligible amount of water from Yarmouk (South).

Figure 13: Drainage directions in the area of interest. White to blue color ramp represents the amount of flow accumulated. In yellow the boundaries of the contributing area related to Mayo Angola.

To delineate depression areas where ponding is most likely to occur and rain seasonal standing water remain, contour lines with a 5 cm step have been derived from the DSM. Existing dismissed channels and natural puddles have been identified, highlighting several areas, such as the square in front of Emergency paediatric clinic, particularly vulnerable to ponding due to local depressions.

5.3 Ponding simulation

The high detail DSM obtained along with the precipitation desk study results have been used as primary input to perform hydraulic simulations of current ponding conditions. The REFLEX model (Rapid Estimate of Flood Extent) has been used for this purpose. REFLEX is a reliable and slim tool able to provide rapid inundation mapping, constraining the possible geo-morphological flood extent with the available flood volume. Flood volume for Mayo Angola has been derived estimating the rainfall volume expected on the drainage basin of interest for a seasonal event.

The current drainage area related to the AOI is estimated at:

$A = 0.78\ km^2$

According to rainfall analysis (Chapter 5.1), the millimetres of rain expected in 24 hours for an intense event (1-in-25 years return period) are:

$R = 65\ mm$

Hence, the estimated volume is:

$V = 50'700\ m^3$

Applying this volume to the REFLEX model, the inundation map shown in Figure 12 is computed. The inundation extent and water depths (white to blue colour ramp) are significant in the area of Mayo Angola.

Figure 14: Ponding simulation on the area of Mayo Angola

5.4 Direct precipitation contribution

A relevant contribution in reducing the direct precipitation contribution to surface flows can be played by rainwater harvesting measures. To assess the feasibility of rainwater collection at the source, roof types have been investigated through imagery detection from drone survey outputs (Figure 15 and 16). 2440 roofs have been classified. Among the roofs identified the 40% can be recognized as Galoos, typical square structures built with clay bricks (yellow marker), the 33% are made of juta and natural cover materials (green marker), the 21% of plastic cover (purple marker), the 6% are roofs made of Galvanized Iron sheets (red marker).

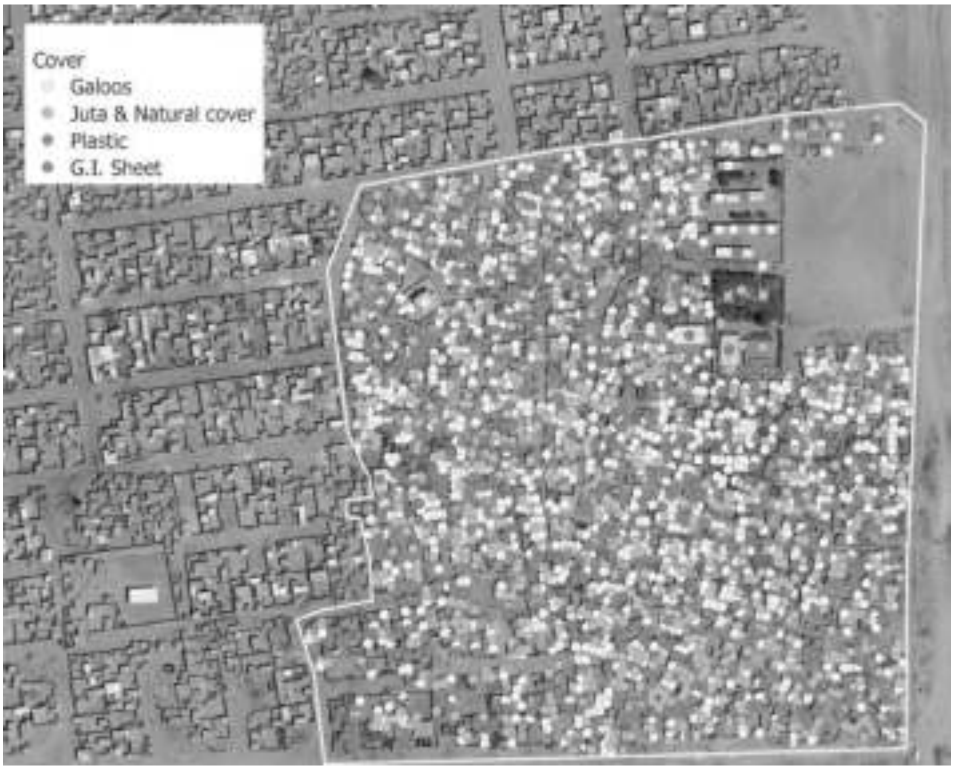

Figure 15: Roof cover identification

Furthermore, this analysis allowed a first estimation of people currently living in Mayo Angola, the most densely populated district of the camp. According to the number of housing units detected and estimating a number of 5-6 inhabitants per house, between 12’000 and 15’000 people are currently living in a 0.1 km^2 area. This high population density value combined with the absence of sewer water systems lead to elevated disease problem during flood events.

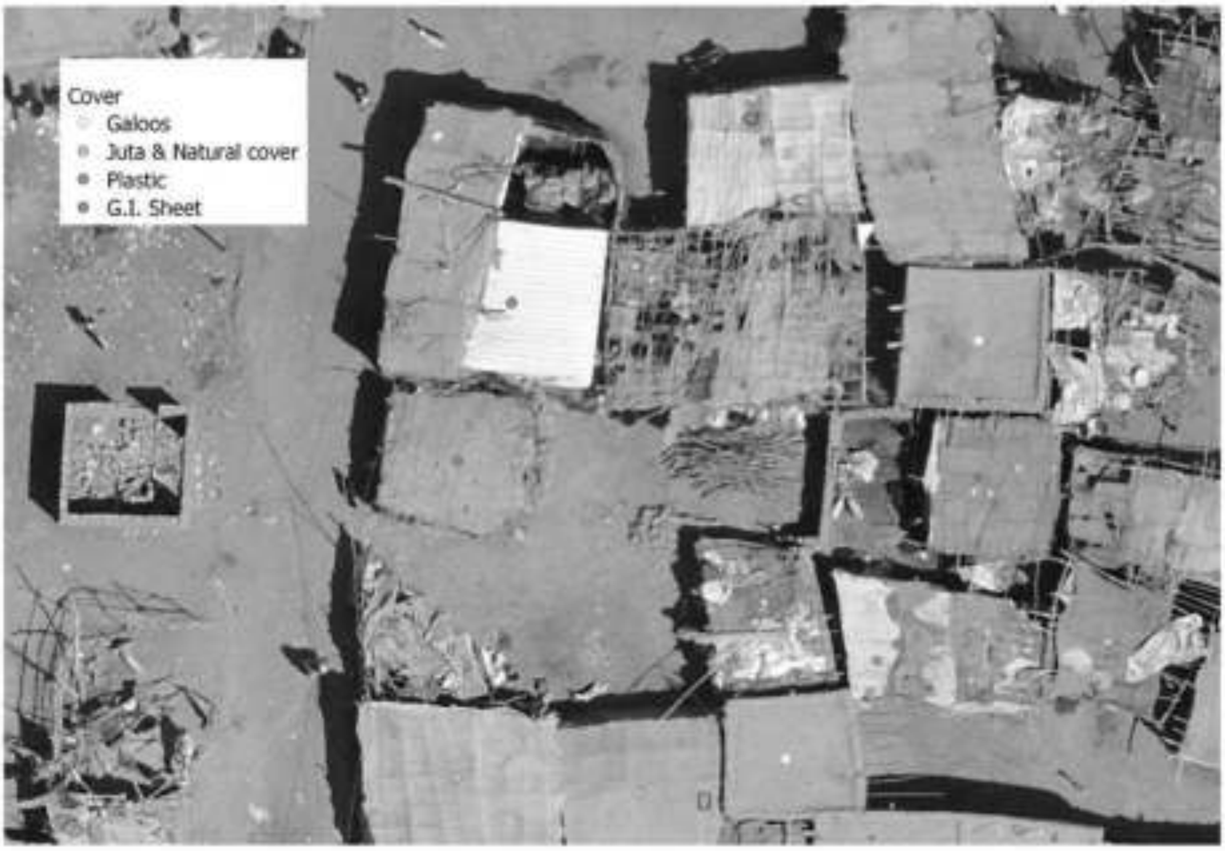

Figure 16: Zoom of an area of Mayo Angola with different types of house roofs

5.5 Ponding Risk Assessment Conclusions

From the Ponding Risk Assessment (Figure 14) some relevant conclusions, to be taken in consideration in defining the proposed mitigation measures (Chapter 6), are:

- The absence of management of sewer water strongly increases the problematics related to rainfall ponding and the identification of solutions;
- The area is extremely flat, with very mild slopes towards the North, this leads to channels with slope of the order of 0.1%;
- Mayo Angola is affected both by direct precipitation and by surface flow from Yarmouk (South);

- Several areas have been identified as depressions, particularly prone to ponding (Emergency square, for instance);
- No rainwater harvesting measures are currently in place in the district of Mayo Angola, which would reduce the direct precipitation contribution to surface flow.

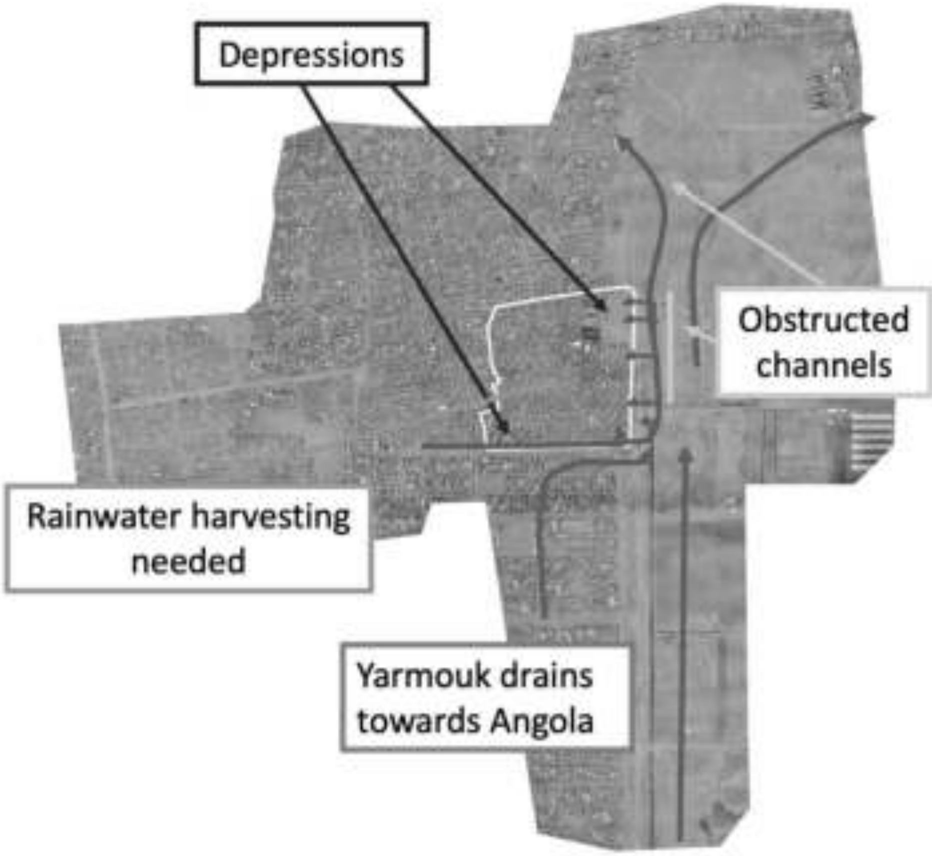

Figure 16: Ponding Risk Assessment main conclusions

6 T3: PROPOSED WATER DISPOSAL SYSTEM FOR THE AOI

The proposed interventions to mitigate the effects of rainfall ponding are:

A. **Channel A**: realization of a new channel in the South part of the Area of Interest (AOI). Channel type 2 (T-2) (see Figure 18 for the cross section), length 660.5 m, profile slope about 0.08%, levee slope 1:1
B. **Channel B**: rehabilitation of the existing channel North of Yarmouk district. Type 2 (T-2) (see Figure 18 for the cross section), length 659.5 m, profile slope about 0.08%, levee slope 1:1
C. **Channel C**: realization of a new channel in the East part of the AOI. Channel type 1 (T-1) (see Figure 18 for the cross section), length 463.1 m, slope about 0.13%. levee slope 1:1
D. **Channel D**: realization of a new channel in the southern side of the Emergency paediatric clinic square. Channel type 3 (T-3) (see Figure 18 for the cross section), length 93 m
E. **Retention pond E**: realization of a retention pond 200 m long, 40 m wide and 3 m deep, levee slope 1:3. The retention pond is needed due to the very low slopes that can be realized (order of 0.1%) that leads to a small capacity of discharge of the channels. Access to the pond must be protected by a fence (E-bis in Figure 21). The sides of the retention pond must be suitably protected, for example with a concrete cover with a steel lattice (to be poured in separated squares, alternated in time), or with reno-type mattresses or metal gabions (e.g. http://www.lucanareti.com/gabbioni-e-rete-paramassi/materassi-reno/).
F. predisposition of a **mobile hydraulic pump** powered by an internal combustion generator / tractor, to move water from the pond (E) to the existing channel OC at the outlet Point 4 (P4). The hydraulic efficiency of the existing outlet channel (OC) is essential to properly discharge water to the Nile river, it should be cleaned of debris and garbage and maintained free of elements that can obstruct the flow of water. The cleaning and renovation of the existing channel (OC) is highly recommended.
G. realization of **4 culverts** (15 m x 4 m) to allow the transit of vehicles (trucks, car, bus)
H. realization of **14 small culverts** (2 m x 4 m) for pedestrian crossing
I. **reshaping** of the **square** facing the Emergency paediatric clinic, slope toward North-East and realization of an elevated access road to the clinic

J. **reshaping** of two internal **roads/squares** in the South part of the AOI particularly prone to flooding
K. **reshaping** of traffic **roads**, with correct slope to convey water into the proposed channels
L. construction of an **elevated platform** for positioning the hydraulic pump

Figure n. 17 reports an overall planimetry of the proposed channels and ponds.

Figure n. 18 reports the profile of the proposed channels and ponds.

Figure n. 19 reports the section and shape of the trapezoidal channel.

Figure n. 20 reports the section and shape of the proposed pond.

Figure n. 21 shows dimension and shape of a traffic culvert.

Figure n. 22 reports an overall planimetry of the proposed reshaping intervention.

Moreover, is highly recommended the use of rainwater harvesting tanks to collect water from roofs before it reaches grounds. Galoos roofs seem appropriate for this purpose. This water can be used for domestic use. Storage devices must be covered to prevent the storage being used as a breeding location of vectors. Use a black plastic tank is recommended to reduce growth of bacteria as the tank will be dark inside.

Figure 17, overall view of the proposed intervention. In red are represented the channels (A, B, C, D), dashed red line for the existing channel OC, outlet of collected water; white boxes are the 4 culverts for vehicle transit; in blue the 15 culverts for pedestrian transit. E identify the retention pond. Channel A and Channel B convey water in channel C. Channel C receives also water from channel D and bring water to the retention pond E. Then, collected water is disposed in the existing channel OC using a hydraulic pump (F). P1 to P4 are the relevant points reported in the longitudinal profile of Figure 18

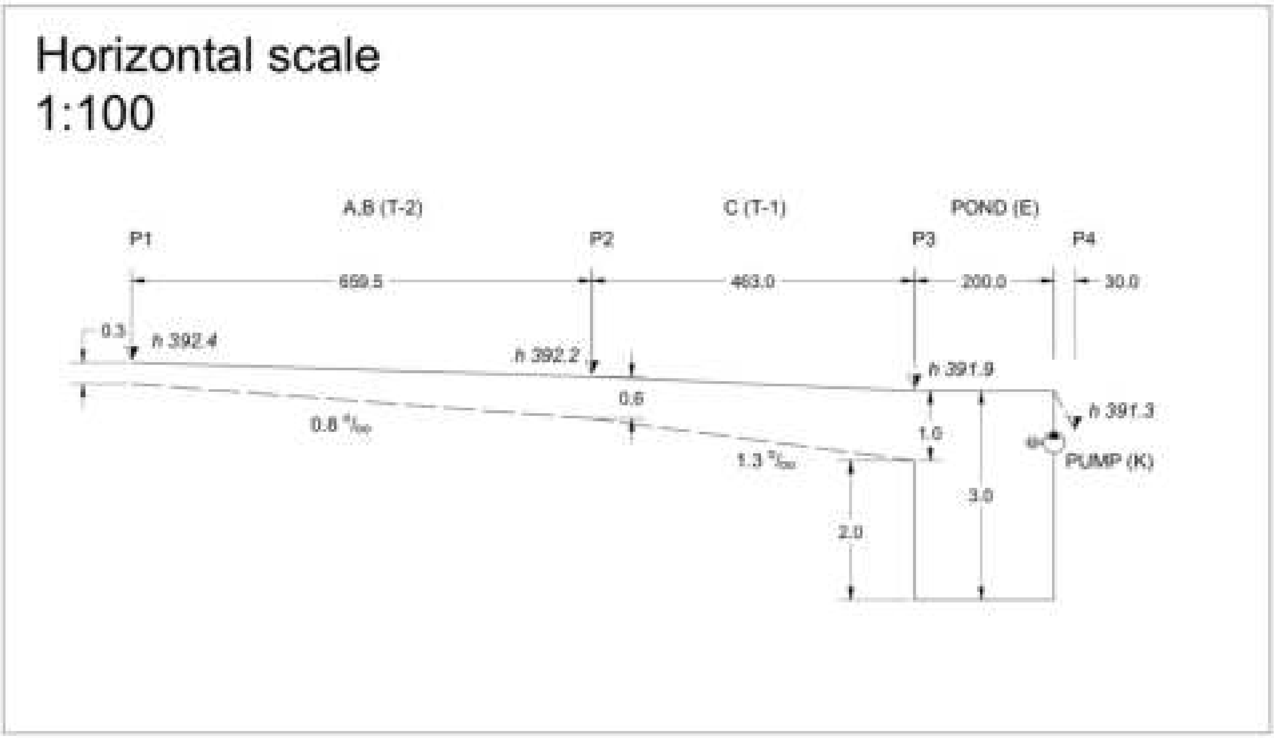

Figure 18, proposed channels profile. The channels A and B have the same slope and are 659.5 m long; channel C is 463.0 m long; retention pond E has a depth of 3 meters. P1 to P4 locations are reported in Figure 17.

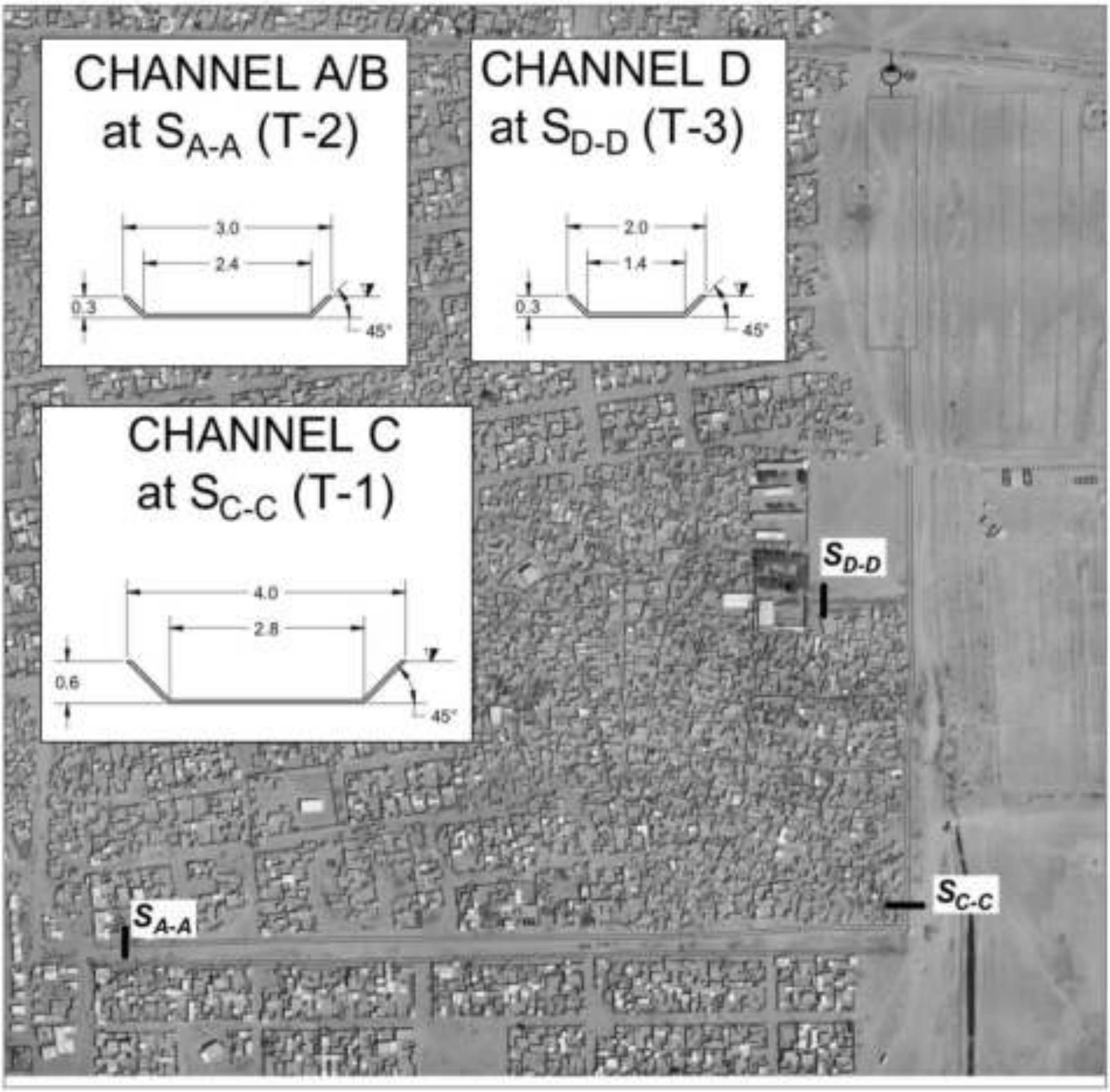

Figure 18, cross sections of the channels A/B, C and D, with location of sections displayed on the AOI map

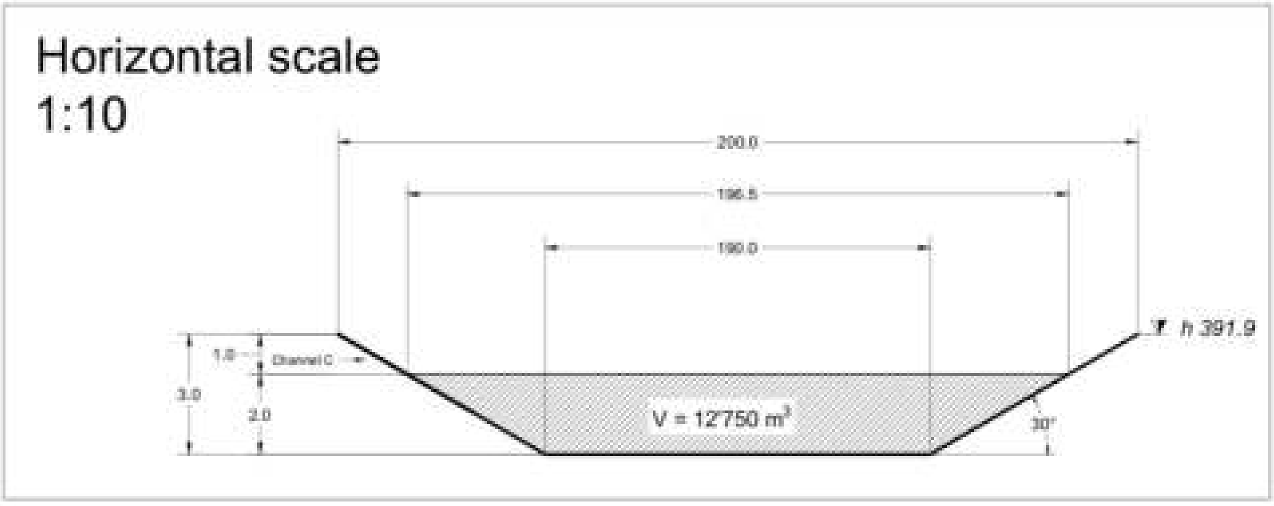

Figure 19, section of proposed pond (E).

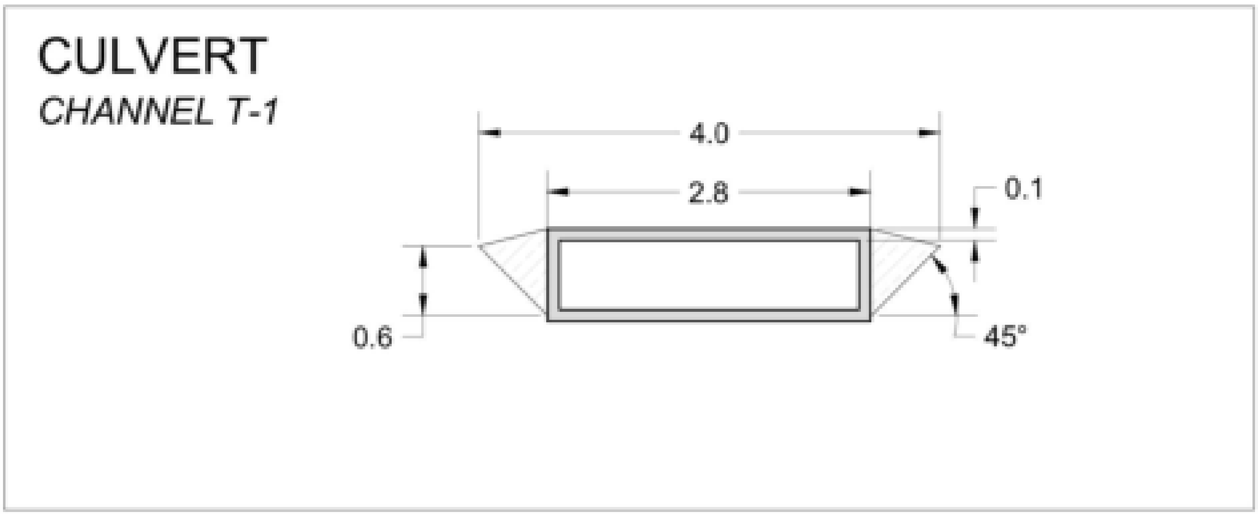

Figure 20, section of traffic culvert.

Figure 21, overall view of the proposed reshaping intervention: (I) Emergency paediatric clinic square; (J) internal ponding-prone roads/square; (K) reshaping of traffic roads on the side of the new channels and (L) an elevated platform for pump positioning. Furthermore, (Ebis) indicates the fence needed to protect access to pond (E)

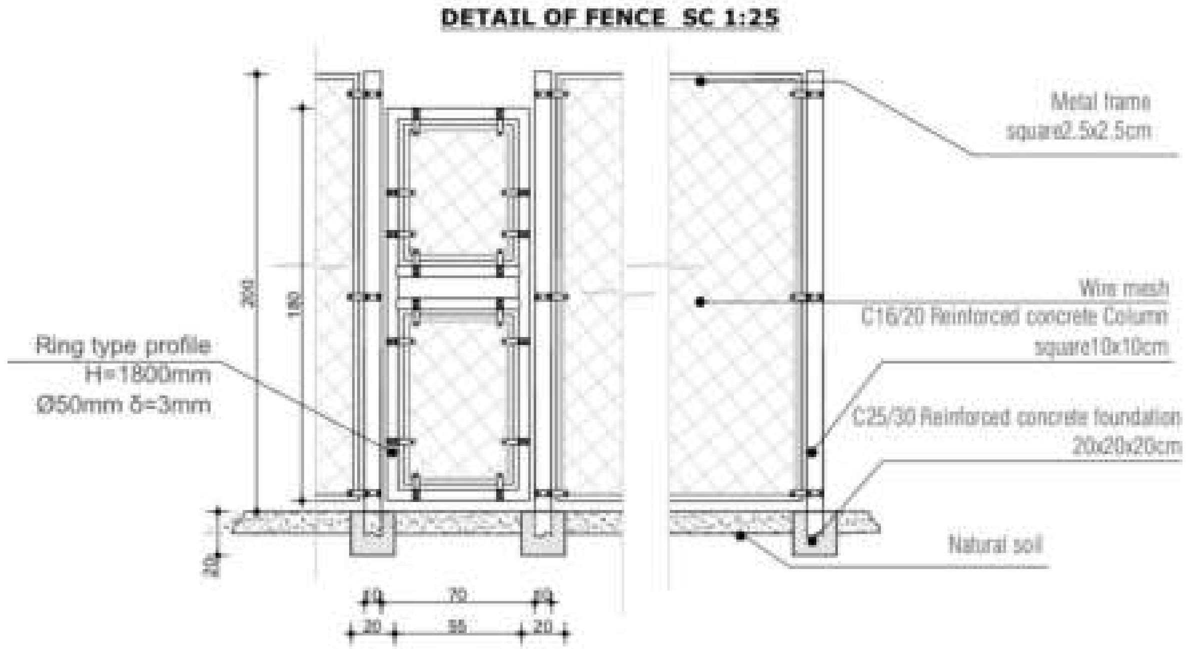

Figure 22, example of fence for the protection of the retention pond.

Table n.1 shows an estimation for the excavation/reprofilation. Table n.2 shows a preliminary estimation of additional costs for construction works or materials.

Table 1, preliminary estimation for excavation/reprofilation

Channels A+C+D	
Total length of excavation for new channels A+C+D [m]	1355
Channel Section Area T1 (C) [m^2]	2.72
Channel Section Area T2 (A) [m^2]	1.21
Channel Section Area T3 (D) [m^2]	0.51

Total volume of excavation A+C+D [m^3]	2109.3
Channels B	
Total length of rehabilitation of existing channel B [m]	659.5
Channel Section Area T2 [m^2]	1.21
Total volume of excavation B (0.6 is a coefficient of reduction that consider that the channel is already partially present) [m^3]	801*0.6=480
POND E	
Excavation of retention Pond E [m^3]	20’453
REPROFILATIONS I+J+K	
Excavation for Emergency square reprofilation (I) [m^3]	500
Excavation for depression areas reprofilation (J) [m^3]	260
Excavation for roads reprofilation (K) [m^3]	2100

Table 2, cost estimation for construction works and material - to be filled and completed using local costs.

Element	**Unit cost**	**Number of units**	**Total cost**
Traffic culverts		4	
Pedestrian culverts		12	

Hydraulic pump (F)		1	
Elevated concrete platform for pump F		1	
Fence for retention pond E		480 m long	