PERFORMANCE ASSESSMENT OF URBAN DRAINAGE SYSTEMS OF HOLETA TOWN USING STORMWATER MANAGEMENT MODEL (SWMM).

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ABSTRACT

The general objective of the study was the Performance Assessment of Urban Drainage Systems of Holeta Town using the Stormwater Management Model (SWMM). The catchment that contributes runoff areas, weighted runoff coefficient was delineated using Arc GIS 10.3 tool. The Stormwater Management Model (SWMM 5.1) was applied to simulate the water level in the links and junctions by considering the current land use condition. The intensity duration frequency (IDF) curve was developed by using log-Pearson Type III to analyze rainfall and the consequent peak runoff for different return periods using a rational method. The existing storm drainage systems of Holeta Town were: lack of well-connected drainage lines, solid and liquid wastes were directly disposed into the storm drainage system, which results in decreasing the efficiency of the system, unavailability of drainage systems at the proper place. Additionally the awareness of the community towards such an issue was less, the major percentage of drainage system performs severely degraded, e.g out of 100%, at Birbisa Siba 50.75%,at Sadamo area 41.384%,at Burka Harbu 63.225% and at Tulu Harbu 42.42% were severely degraded. This result shows the majority of the drainage systems are not adequate to carry the design flood based on intensity with a return period of 10 years. The SWMM output indicates that in most of the junctions, the flood level was greater than the designed water level.

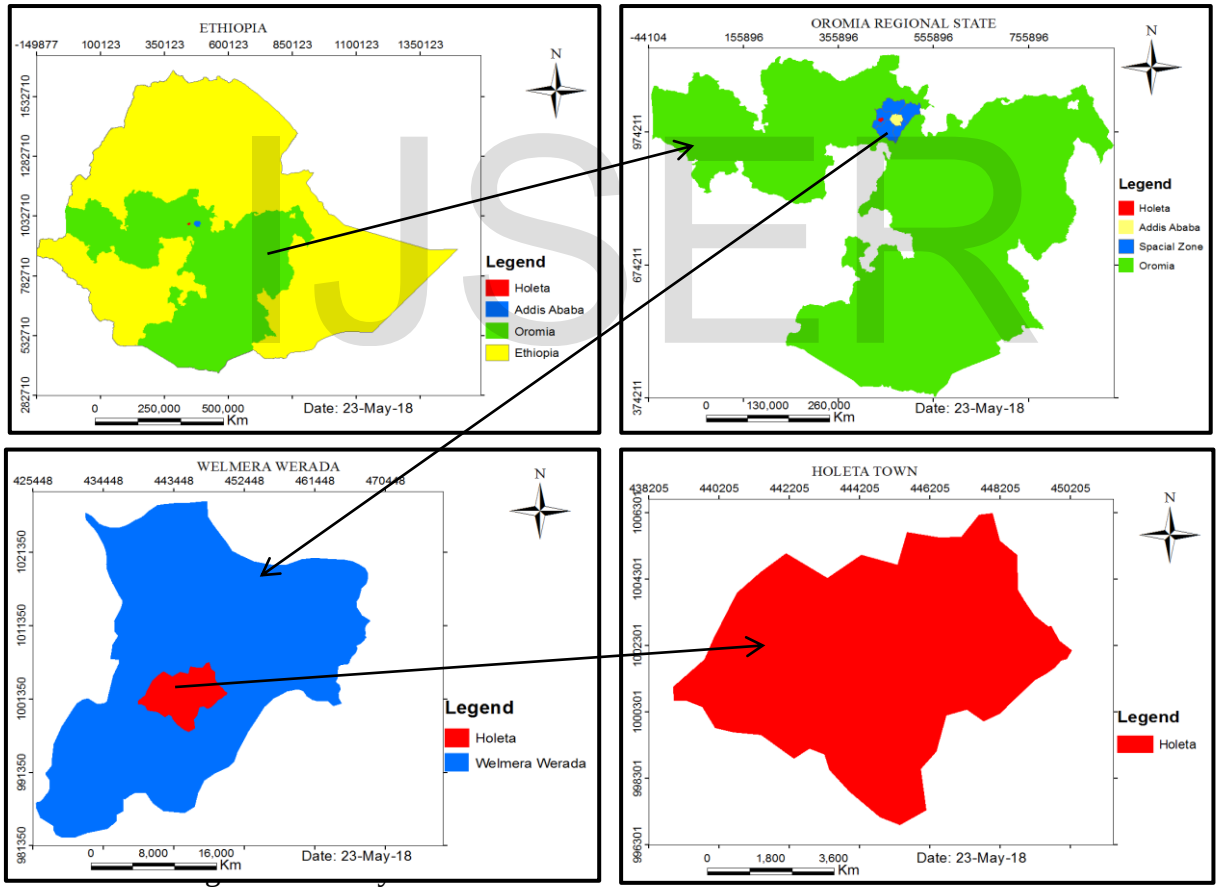
1. Background

Urban storm water drainage facilities are part of the urban infrastructure elements and design of these facilities require due attention. In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at source, flood protection, and safe disposal of excess water/runoff through proper drainage facilities becomes essential (AASHTO, 1991 et al). The urban stormwater influences the service life of urban infrastructures and the rainfall intensity and characteristics of the catchment area are the major factors for designing urban stormwater drainage facilities. These facilities have a paramount advantage to safely dispose of the generated floods to ultimate receiving systems. Stormwater management is concerned with the collection, conveyance, storage, treatment, and disposal of storm runoff in a way that minimizes accelerated channel erosion increased flood damage. Proper drainage is an important factor that should be given due consideration in the design of a highway since inadequate drainage facilities can lead to premature deterioration of the highway and the development of adverse safety conditions (Mukherjee, 2014). The major causes of flooding as the blockage of urban stormwater drainage lines along with inadequate/poor integration between road and urban stormwater drainage infrastructures. In addition,with urbanization, impermeability increases with the increase in impervious surfaces (i.e. residential houses, commercial buildings, paved roads, etc.), drainage pattern changes, the overland flow gets faster flooding and environmental problems like land degradation increases. It is a crucial problem facing the existing and future road infrastructure (Belete, 2011). In order to conduct flooding and early warning and take some measures, we have to have a well prepared modeling urban drainage network (Xingpo & Suiqing, 2008).This study aims to identify the bottleneck of the urban drainage networks, practically evaluate the overall service performance of the urban drainage networks and provide possible suggestions for improving the hydraulic performance of the whole urban drainage system. Hence, a case study using Storm Water Management Model (SWMM) and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies and investigations to the major storm water drainage problems areas in the town.

2. Study area

Holeta town is located in the Western Shoa part of Ethiopia, in Oromia National Regional State, surrounding Finfine at a distance of 30 km from Addis Ababa. Its astronomical location is at

9°3'30" to 9°4'30" North latitude and 38° 29'00" to 38°29'30" East longitude. And its altitude ranges from 2400-2448 m above sea level. Holeta town separated from Welmara woreda with distinct boundaries and administration with a total area of 6,185 hectares. From this total area 1,645.21 hec is residence, 92.78 hec commerce, 705.09hec Service, 12.37hec Administration, 309.25hec Industry, 1,218.45hec. Road and Transport, and 2,201.85hec are Environmental sensitive area. The climate is Tropical Mountain, with the air temperature ranging from 11°C to 26°C with the mean of 20°C. However, the annual rainfall ranges between 900-1100mm.And serves hinterland areas as a business and service center and about 16,785, and 34,701 in the years 1994 and 2007 population and housing census respectively. It is expected reach at about 63,788 and 110,943 in 2018 and 2028 respectively. The population average growth rate of 5.5%. The overall catchment area largely dominated by Eutric Nitosols soil.



3. Materials and methods

3.1. Data collection and Analysis

The main data used for the assessment of Urban Drainage Systems of Holeta town formations were surveying data, drainage depth data, climate data, location and geologic map of the formations. A 20 m by 20m resolution ASTER Global Digital Elevation Model was obtained from the NASA website also obtained from Ethiopia mapping Agency. This data was projected to Transverse Mercator (UTM) on a spheroid of WGS84 and it was in a raster format to fit into the model requirement. Sub-catchment delineation and estimation catchment parameters such as area, slope gradient, slope length of the terrain of natural drainage network characteristics such as channel slope, length, and width were derived from the DEM. In order to successfully delineate a watershed boundary, it is needed to visualize the landscape as represented by a topographic map. This map helps to examine the elevation, determine flow direction and flow length of the catchment areas. To determine areas with and without drainage system in Holeta stream catchment by integrating with Google Earth. Consequently, tape meter used to measure the existing stormwater drainage lines depth, width, and diameter which helps to evaluate the capacity of the drainage system. Google Earth used to verify watershed and divides of catchments of the study area, in order to compare and identify the different land features (Residential area, Commercial area, Mixed residence and Vegetable area, road(Asphalt/Cobblestone/Gravel, Earthen and drainage),Green area) within different time of period and gives to some interpretation of Landsat images of the urban environment especial land use and land cover, in order to obtain Land use area A (ha), Runoff coefficient (Ci), Weighted runoff coefficient (Cw), Catchment area (ha) . It is also used to have the most recent data of the study area in the urban drainage system of the catchment as well as sub-catchment. In this study, the rational method and Stormwater management model (SWMM) was used for the design flood computation and its analysis. The rational method would be compared with the existing carrying capacity of the main drainage canal system for a certain return period of rainfall intensity. Whereas the stormwater management model is one-dimensional models which allow the flow properties to vary along or within the channel only rather than to account the changes across the channel (Rossman, 2004).

4. RESULTS AND DISCUSSIONS

4.1. Current Situation of Existing Drainage System in the Study Area

From the result of a field survey, interview and visit, drainage service in the town were inadequate in terms of quality and coverage. Currently, the stormwater drainage management of the town is not efficient as a result of managing problems. Drainage systems are not well connected; are do not as have the capacity to carry large amounts of water, hence resulting in overflowing. In some areas, drainage systems were not provided, and some of the existing drainages have been silted by sand, other rubbish,

and waste materials. Especially the great problem in the study area were lack of waste management techniques (like manholes and trash bin). In the case of Holeta town, the existed manholes were out of service and have been clogged with waste and blocked due to lack of clearance. Additionally, at different places, they were not constructed. As well as a trash bin in the town not adapted. As a result, the runoff that is generated in that sub-basin overflows with a higher velocity which erodes the ditches as well as the road and walkways.

4.1.1. Residential increment and impervious surface

From the total area of land use observed the major percentage of Holeta land use was covered by residential area. That is residential 26%, commercial 15%, asphalt 7%, cobblestone 12%, mixed residences 10%, gravel 16.13%, government compound 3.91%, bare land 3.24%, green area 1.5%, urban forest 1.22% and School 1.68%, playground 0.52% and Health center 1.8% were resulted.

Due to residential increased through the town without drainage system addition, the existing drainage systems become busy and create high runoff through the town. Basically, the residential increment of the Holeta town creates a very high run-off, and a good adequate drainage system would be a proactive method of combating the effect of excess flood in town. Additionally, due to the highly impervious surface as a result of built-up area, the rainfall doesn't infiltrate into the ground. This causes inundation over the entire area, reduce groundwater recharges, a higher velocity which creates scouring of the drainage structures and increases the surface runoff by which it affects those channel that conveys this runoff into the existing drainage systems.

4.1.2. Dumping of solid wastes into storm drainage Systems

Dumping solid waste materials into the drainage system was the other challenge of the stormwater drainage system in Holeta town. Urban litter (alternatively called trash, debris, junk, floatables, gross pollutants, rubbish or solid waste) has become a major problem through the town. It typically consists of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, shopping bags, cigarette packets and remains of chat. As a result of dumping such solid wastes into drains the drainage systems have been clogged and cause flooding over streets and drainage failures, as shown (Fig. 2).

Figure 2: Dumping of solid wastes

4.1.3. Liquid wastes into storm drainages systems

The liquid released directly into the drainage systems were gathering up pollutants along the way including motor oils and gasoline that leak from vehicles, waste from sewer lines and anything also that would float or dissolve in water. Prohibited joining of sewerage system into existing drains was one of the challenges which have been observed in this town. Most of the drainage lines in town accommodate as waste disposal and blocked by liquid and solid wastes. Aside from its' challenge to the drainage system, it could also cause a health problem and also it degrades the visual value of the environment, as shown (Fig .3).

Figure 3: Liquid wastes into storm drainages

4.2. Hydraulic capacity and design of the Existing Drainage Systems.

The land use type and drainage network of the study area was the key point for the result of area, runoff coefficient, rainfall intensity and length of the catchment in order to determine hydraulic capacity. The existing storm drainage facilities were generally classified into closed and open drainage lines and constructed by masonry and rectangular geometry. By applying the field survey, the dimensions of drainage systems were recorded. So that the amount of discharge conveyed in the existing drainage system could be determined by the Manning equation.

4.2.1. Land-use type and Sub-catchment of the study area

A sub-catchment is an area of land containing a mix of pervious and impervious surfaces whose runoff drains to a common outlet point, which could be either a node of the drainage network or another sub-catchment. Then the result from google earth were area of land containing a mix of

pervious and impervious surfaces who's dividing into many polygons. And these polygons classification of land features in Kml are too large to express the spatial distribution of rainfall-runoff production. Then the polygons with Kml are converted to layers by (ArcGIS 10.3) and are continued to divide into much more cells according to the separate social units. The cells are the sub-catchments for calculating rainfall-runoff .Then the total sewer shed can be divided into many polygons.The runoff contribution area of existing drainage canals was delineated based on the flow direction map by indicating the outfall boundary of the study area. The main result from sub-catchment area delineation was weighted runoff coefficient of each landuse those contribute the catchment of study area shown as (Fig.5).

4.2.2. Drainage network of study area

All runoff generated from the catchment would not flow towards the outlet. Because of the limitation that in urban environment runoff flows not only on surface but it also flows through manmade drainage structures such as roadside ditches. With the limitations in mind the catchment delineation can be taken as worst case scenario. So the proposed and existing drainage facility resulted based on the possible out flow direction. As a result the whole catchment of Holeta town has three outfalls boundary; Outfall at Wajitu boundary, Birbirsa Siba and Mada Gudina boundary presented in (Fig. 4). Sub catchments were delineated based on the flow direction of the drainage structures of both right and left directions.

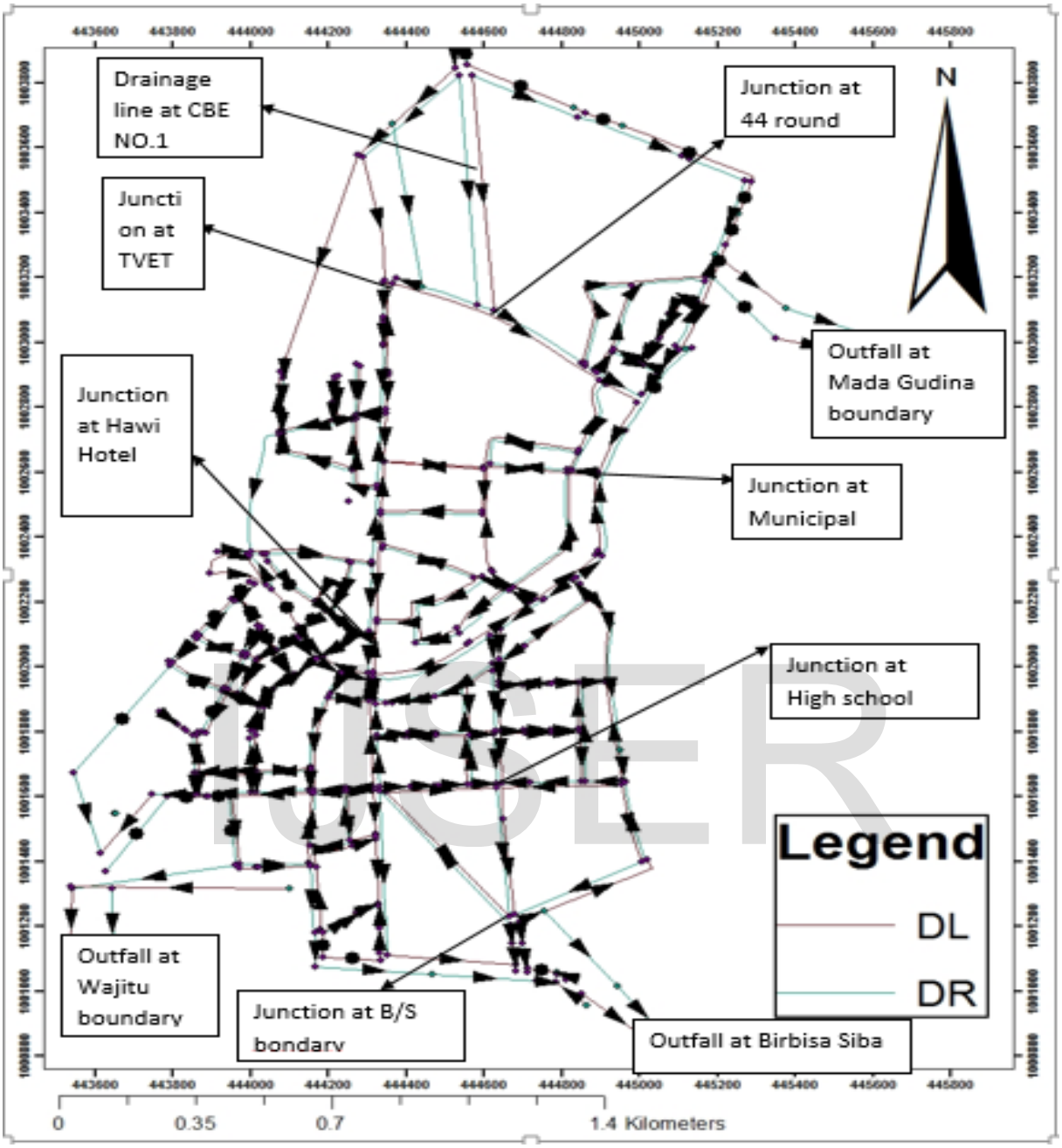
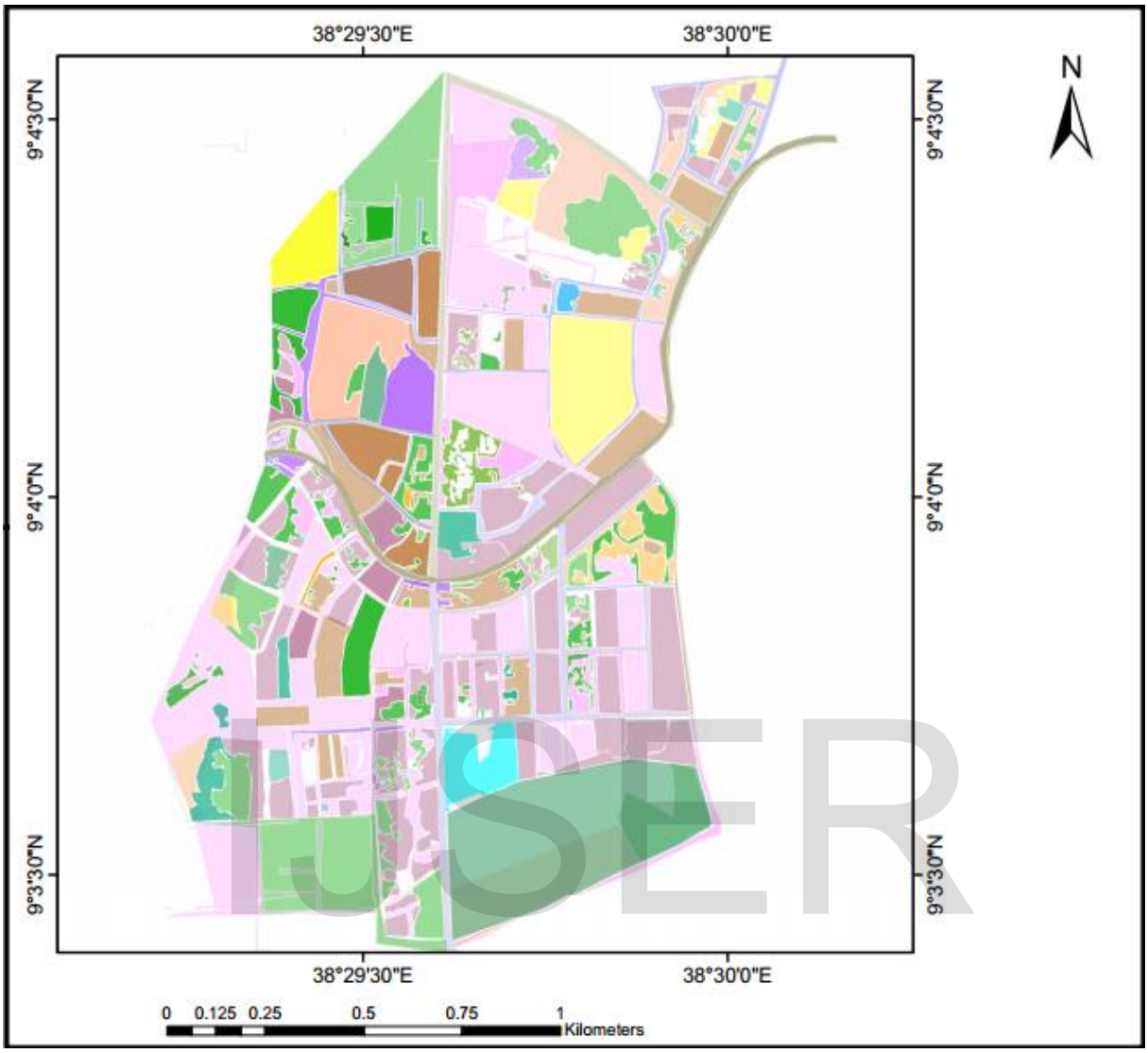


Figure 4: Drainage Network



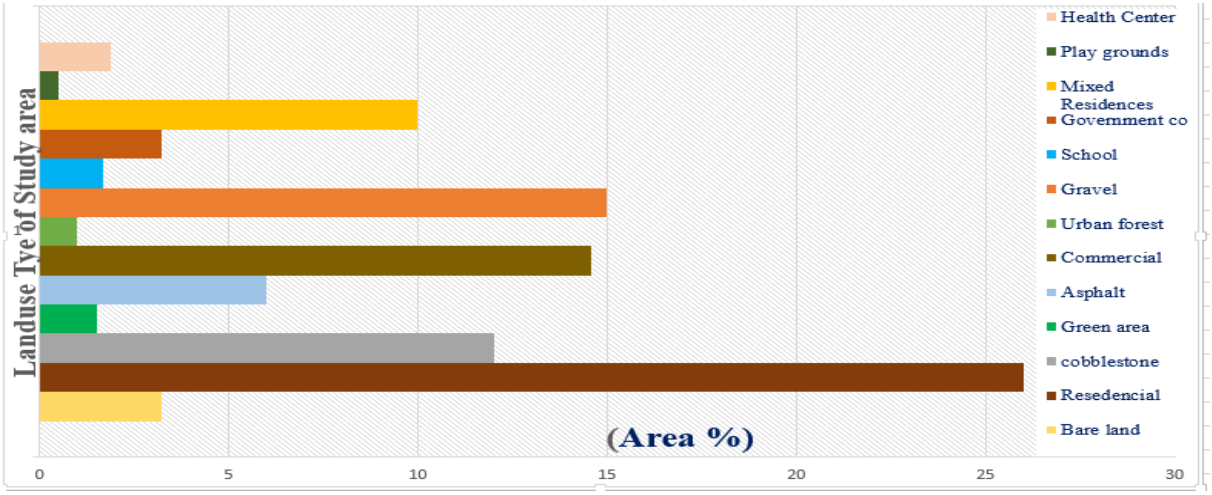


Figure 5: Land-use type of study area

4.2.3. Peak discharge of study area

Proper selection of the runoff coefficient calculated depending on the different land cover that contributes to the sub-catchments of the drainage area .The portion of the total rainfall that would reach the storm drains depends on the percent imperviousness, slope and ponding character of the surface. The frequency analysis of the extreme rainfall events analyzed using the Log-Pearson type III distribution and then peak flood discharge is calculated using a rational method as presented in table 1.

ID of SC	SC-Area (ha)	TC (min)	Intensity 10yr	Intensity 25yr	Intensity 50yr	Intensity 100yr	Weighted runoff	Q(m^3/s) 10yr	Q(m^3/s) 25yr	Manning Q (m^3/s)
GQsc-1	3.26	5.72	140.9	162.75	179.56	194.35	0.6734	0.86	0.99	1.39
GQsc-2	4.17	15.4	101.7	117.1	128.5	139.7	0.78	0.92	1.06	1.84
GQsc-3	6.77	20.3	89.3	102.9	112.8	122.7	0.75	1.26	1.45	2.06
BHsc-1	5.53	18.7	93.3	106	116.8	126.7	0.6835	0.98	1.11	0.59
BHsc-2	6.57	13.9	108.3	124.5	135.5	146.7	0.748	1.48	1.70	0.61
BHsc-3	15.73	12.3	111.3	127.5	138.5	149.7	0.773	3.76	4.31	2.63
WJsc-1	12.91	6.67	139	161	168	193	0.7835	3.91	4.53	1.30
MGsc1	11.64	14.5	105	120.8	132	143.2	0.8180	2.78	3.20	2.31
MGsc2	0.18	25.3	79.7	91.8	100.7	109.5	0.7641	1.23	1.3	0.46
THsc1	19.46	17.3	95.3	108	118.8	128.7	0.6692	3.45	3.91	1.75
THsc2	22.30	21.1	87.3	100.9	110.8	120.7	0.7133	3.86	4.46	1.55
Ssc1	2.84	7.78	137.5	159.6	166	191.65	0.8837	0.96	1.11	0.60
BWsc1	3.71	18.2	93.5	106.5	117.3	127.2	0.7474	0.72	0.82	0.63
BSsc1	11.30	6.51	139.2	161.23	168.3	193.32	0.8912	3.86	4.46	3.76
BSsc2	3.16	12.8	111.6	127.88	138.88	150.7	0.8558	2.81	3.387	2.97
BSsc3	15.54	14.3	105	120.8	132	143.2	0.7917	3.59	4.13	3.41

The peak discharge of the study area estimated by using a rational method from currently estimated runoff for design 10yrs and for check (review) 25 years considering the sub- catchments that contribute drainage area with the outfall of the study area. Where GQsc = Goro Qerransa sub-catchment, BHsc = Burka Harbu sub-catchment, MGsc = Mada Gudina sub-catchment, THsc = Tulu Harbu sub-catchment, Ssc = Sadamo sub-catchment, BSsc = Birbisa Siba sub-catchment, WJsc = Wajitu sub catchment.

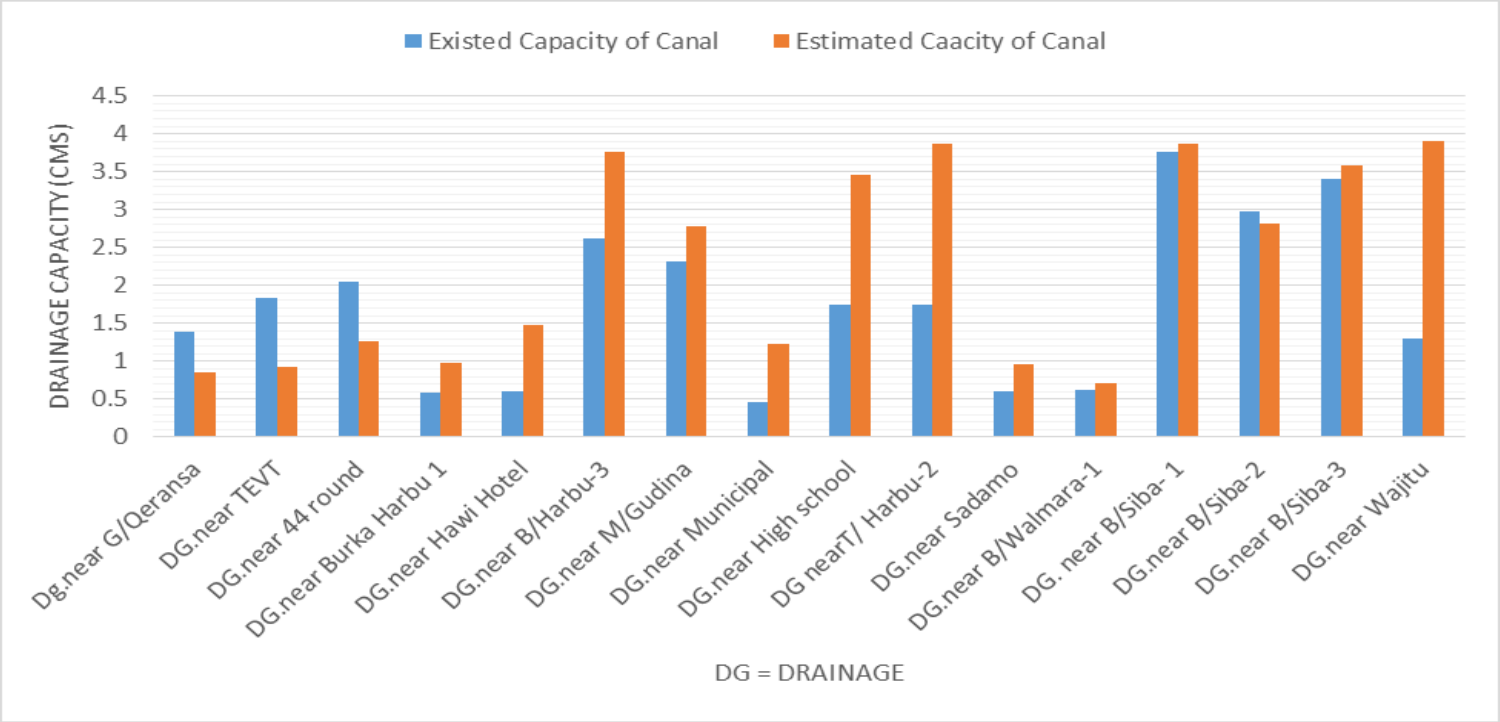


Figure 6: Capacity of Canal existed and estimated

The result obtained for a design period of 10 years as in (Fig.6), indicated that the capacity of existing drainage at Goro qerrensa, around 44 and at TVET were adequate. Whereas at Hawi Hotel, Municipal, Burka Harbu, Burka Walmara, Tulu Harbu, Wajitu outfall, High school, Sadamo and at Mada Guddina outfall, Birbirsa Siba outfall the estimated drainage capacity of current runoff was higher than the existing one. That means overflow has happened in this area.

4.3. The Storm Water Management Model simulation

4.3.1. Water Level and Flood Level in the Junctions

I). Drainage near to High School

The maximum designed water level of drainage canal of junctions 14 and 15 near to high school were 1 m and 1.15 m respectively. The flooding level attained with 3hrs rainfall intensity injunction 14 is 1.1 m and injunction 15, 1.25m. Based on the simulation result of the model for the current land use condition, the designed canal depth was insufficient. Therefore there is the overflow of the water at junctions 14 and 15 due to inefficient canal capacity (Fig.7).

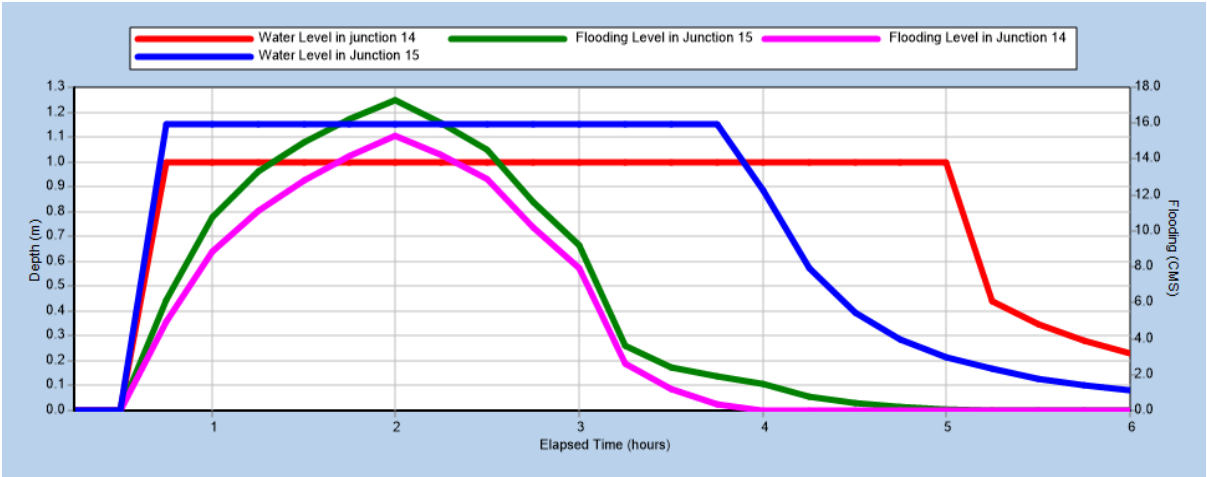
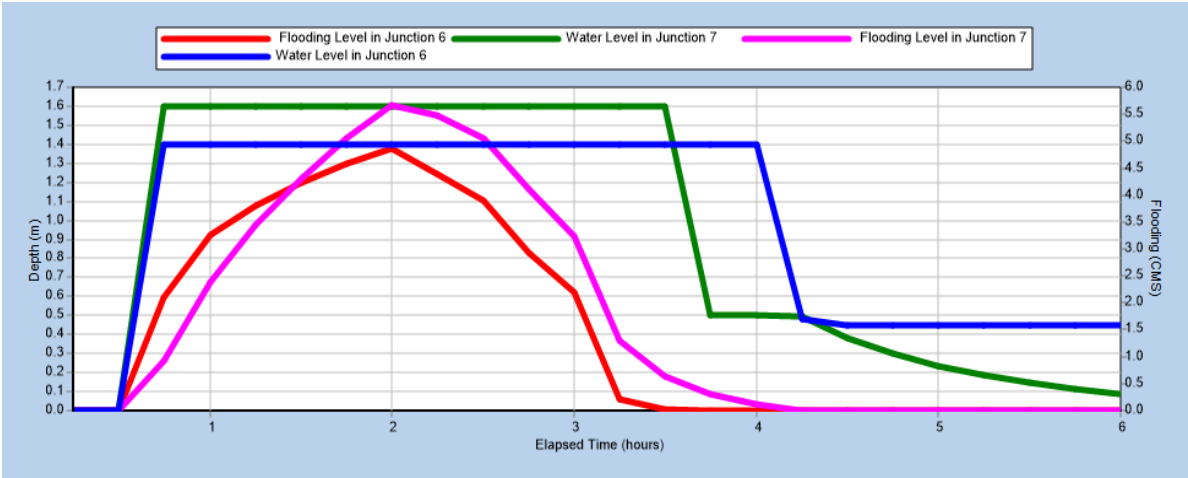


Figure 7: Designed water lev*el* and flood in junction-around High School

II). Drainage around 44 areas and TVET College

At around 44 areas the maximum designed water level of drainage canal of junction 6 and junction 7 were 1.4 m and 1.6 m and the flooding level attained with 3hrs rainfall intensity of each junction was equal to the maximum designed water level. As a result of simulation indicates the designed canal depth was sufficient and show that there is no flood at this location. Also near to TVET College, the designed water level of junction 2 and 4 were 0.4 and 1.65 m whereas the flooding level at the same junctions were 0.98 and 1.65 m respectively. That means the designed canal depth is sufficient. The simulation result shows that there is no flood around the area (Fig. 8).



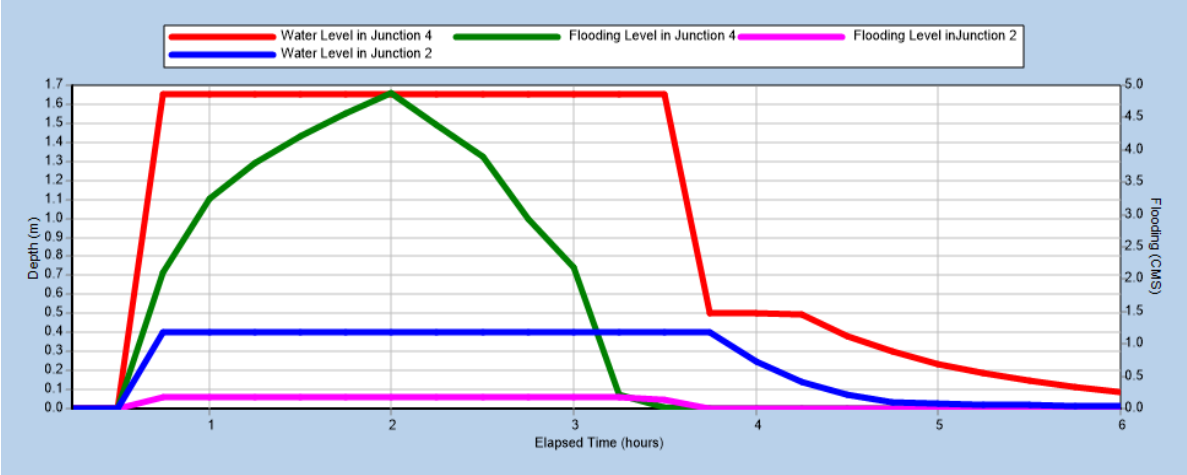


Figure 8: Designed water level and flood injunction around 44 areas and TVET College

III). In front of Holeta Municipal up to water supply and sanitation office

At in front of Holeta Municipal, the designed Water level of drainage canal of junction 8 and 9 is 1.15 and 1m respectively and the maximum flooding level for the 3hrs of rainfall intensity is greater than the maximum designed water level of junction 8 which is 1.25 m. The result of simulation indicates the maximum designed water level drainage canal of junction 8 was insufficient and the occurrence of overflow. Additionally, the maximum flooding level of junction 9 is less than of the maximum designed water level. That is the designed water level of drainage canal of junction 9 is sufficient and there is no overflow as the result of the model, but from the area of junction, the overflow was happened due to lack of management (Fig.9).

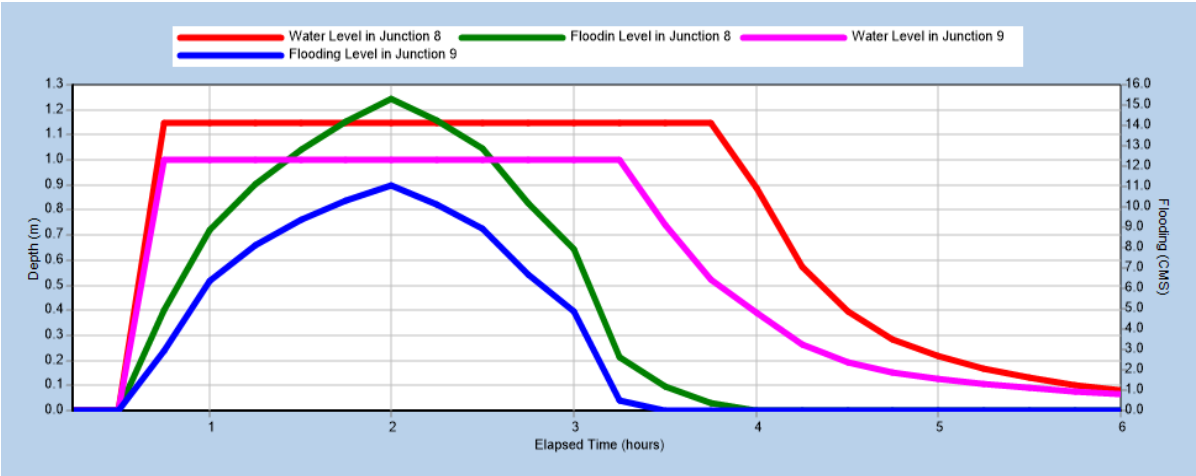


Figure 9: Designed water level and flood injunction around Municipal

IV).Drainage around Hawi Hotel

The maximum designed water level of drainage canal near to Hawi Hotel of junction 12 and 13 was less than the flooding level attained with 3hrs rainfall intensity. And the result shows that there is the overflow of water due to insufficient capacity of designed drainage canal of junctions 12and 13 around Hawi Hotel (Fig. 10).

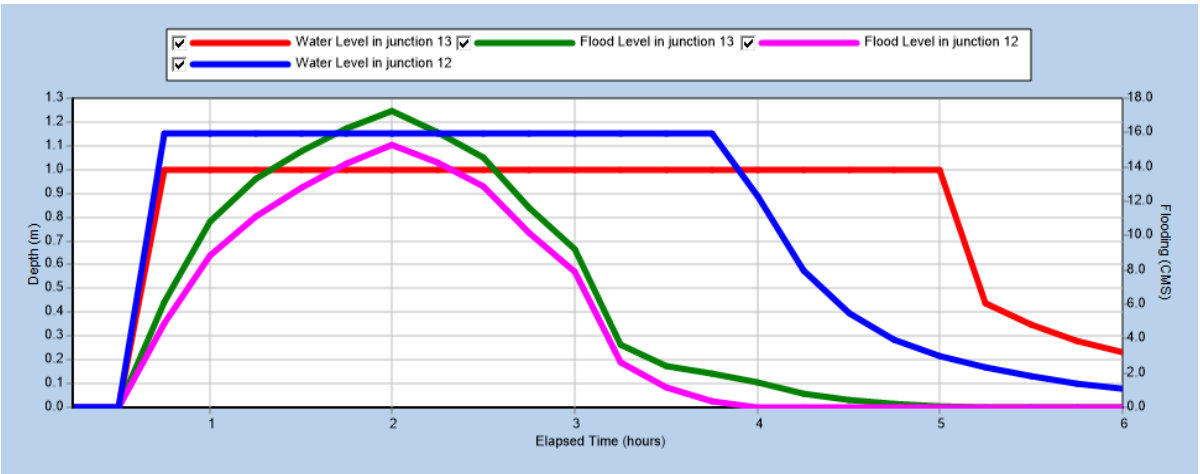


Figure 10: Designed water level and flood injunction around Hawi Hotel

V).Drainage near to Goro Qeransa

The designed water level drainage canal of junctions 1, 2, 3 and 5 were 0.5, 1.15, 1 and 2.4 m respectively. The maximum flood level of each junction is less than the maximum designed water level of the drainage canal. So that the designed water level of drainage canal depth around Goro Qeransa is sufficient, the simulation result shows that there is no flood (Fig.11).

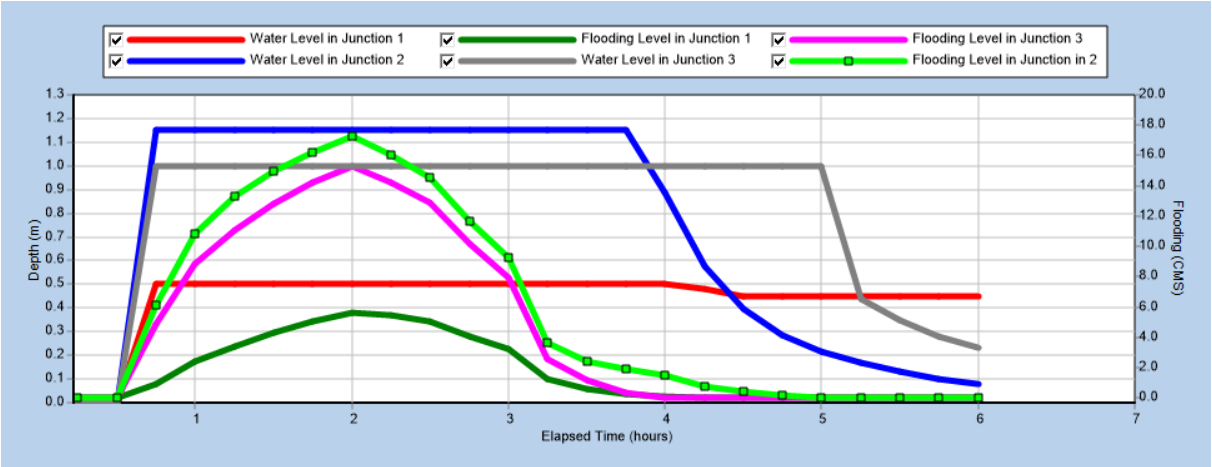


Figure 11: Water level and flood injunction at Goro Qerransa

VI).Drainage near to Burka Harbu

Figure 30 shows the designed water level of drainage canal of junctions 10 and 11 were 1 and 1.15 m respectively. And the maximum flooding level of each junction is greater than the designed water level of drainage canal depth. So that the designed canal depth of junction 10 and 11 near to Burka Harbu is insufficient and the simulation result shows that there is the overflow of the water around the area (Fig.12).

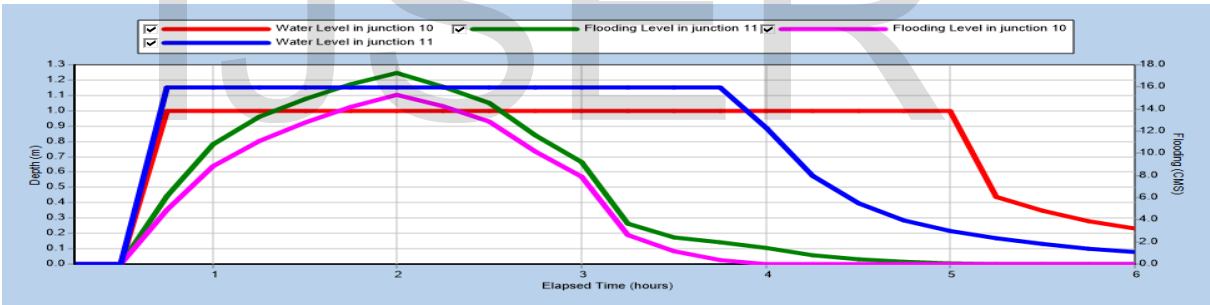


Figure 12: Water level and flood injunction at Burka Harbu

VII).Drainage near to Tulu Harbu

The maximum designed water level drainage canal of junctions 15,17 and 18 were 1,2.5 and 1.8 m and the flooding level of each junction 1.2,2.23 and 2m respectively. The designed canal depth of junctions 15 and 18 was insufficient and the simulation result shows that there is overflow. And the flooding level injunction 17 is less than the designed water level. So that the simulation result shows there is no overflow of the water around the drainage canal of junction 17 Tulu Harbu area. But from the area that we have seen of junction 17 filled by sediment and other rubbish materials and result overflow of the water around the area.

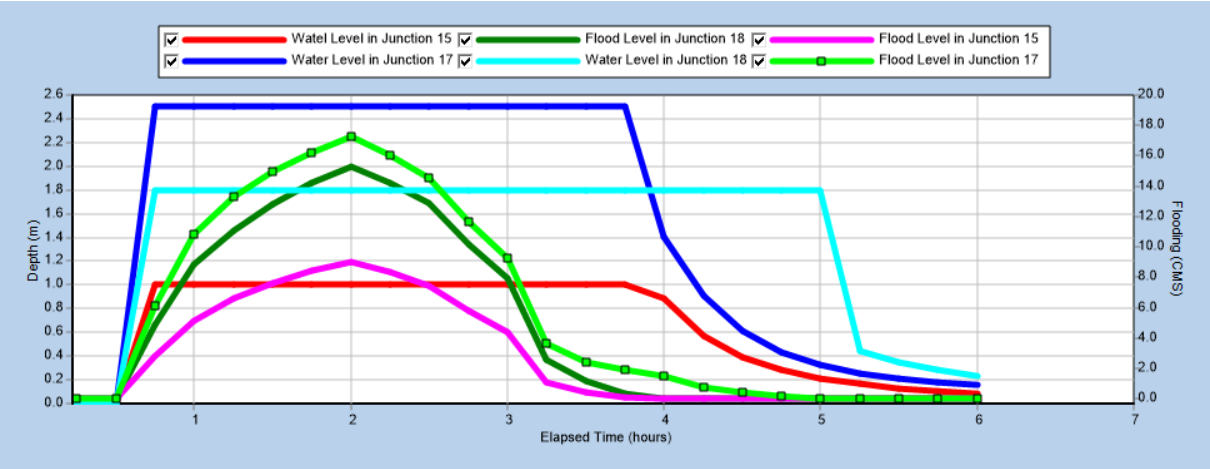


Figure *13*: *Water level and flood injunction at Tulu Harbu*

VIII).Drainage at Sadamo

The designed water level drainage canal of junctions 15 and 19 were 1 and 1.1 m respectively. The designed canal depth of each junction was insufficient and the simulation result shows that there was a flood occurrence around the Sadamo drainage canal area (Fig.14).

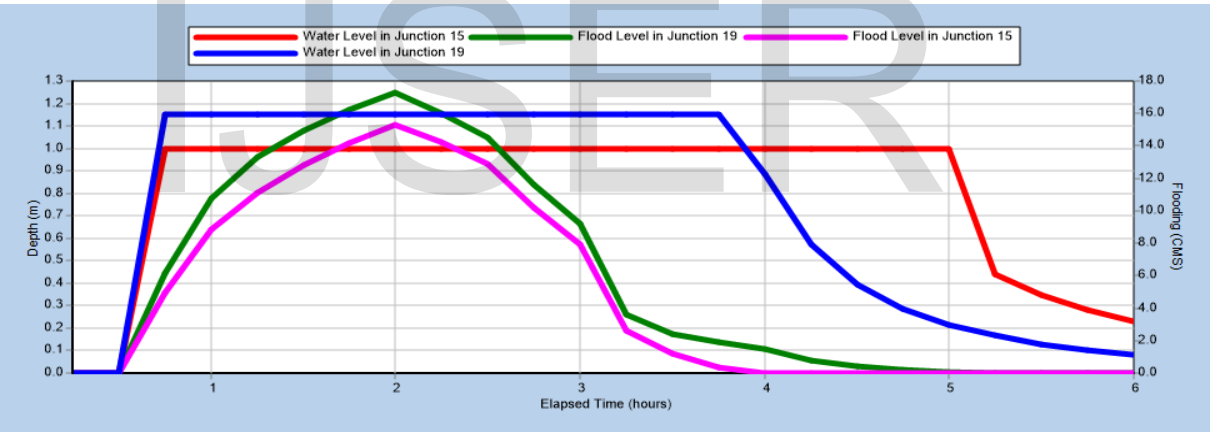
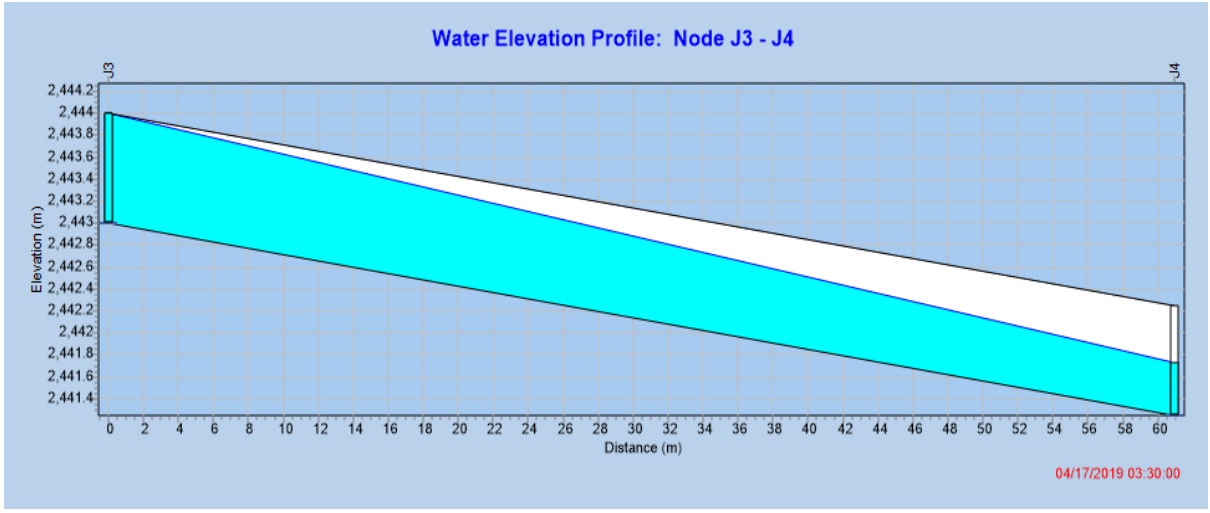


Figure 14: Water level and flood level injunction at Sadamo

4.3.2. Water depth and flow in the Links

I). At Birbisa Siba Outfall.

Figure 15 shows that the flow within the link and nodes at Birbisa Siba Outfall. The simulation result indicates that both junctions (15 and 19) are flooded due to insufficient design water depth. Consequently, the link (C21) is also busy at this time and the overflow of runoff has happened. And the drainage canal that found at the downstream part of Birbisa Siba Outfall (link C3 and Junction 4) are sufficient to carry the generated runoff and also there is no flooding in the Junction 4.



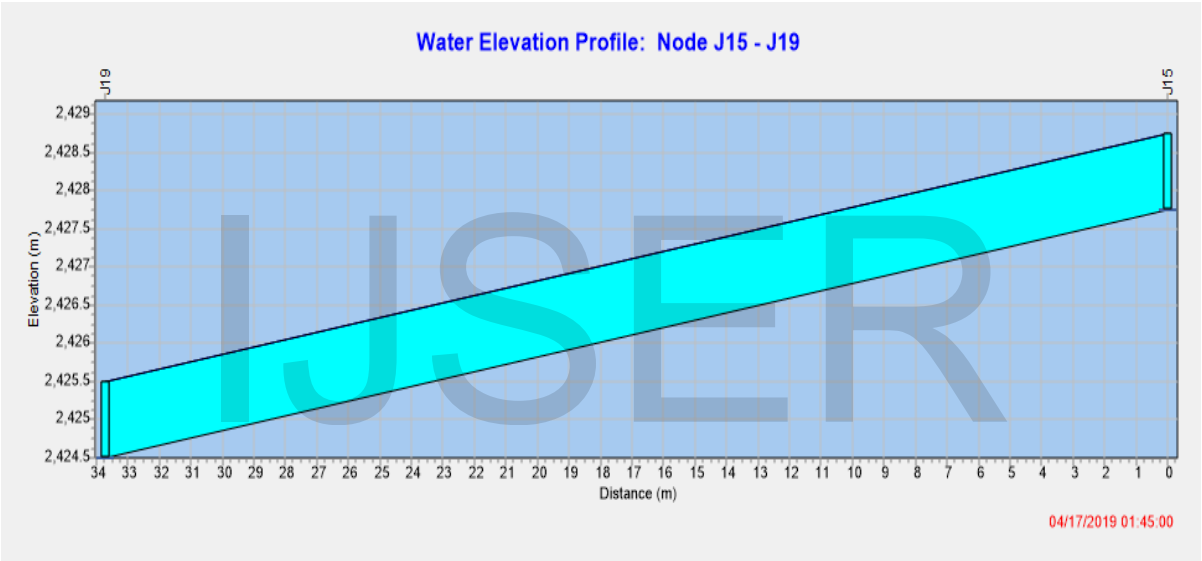
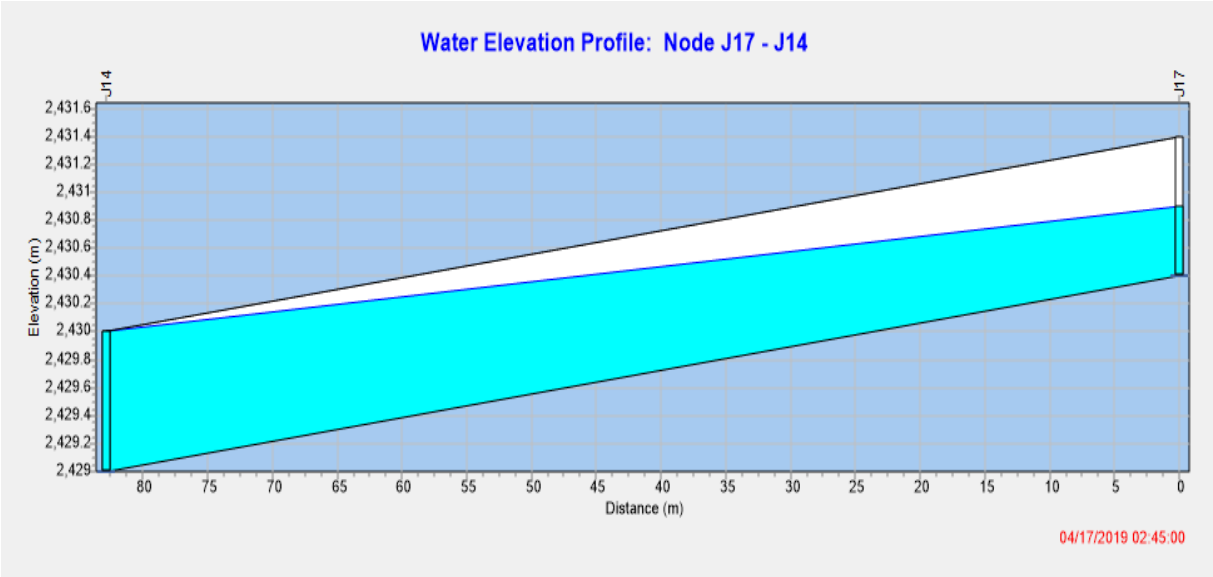


Figure 15: Water Elevation Profile at Birbisa Siba Outfall

II). Drainage towards Mada Gudina Outfall

The drainage canal found an upstream part of the Mada Gudina outfall link (C15, C16) as the simulation result indicates the junctions (16 and 17) are sufficient to carry the generated runoff and also there is no flooding as shown figure 30. But the downstream of the link (C15 and C16) means junctions (10 and 14) are also insufficient for this condition of land use (Fig.16). That means overflow has happened in the area.



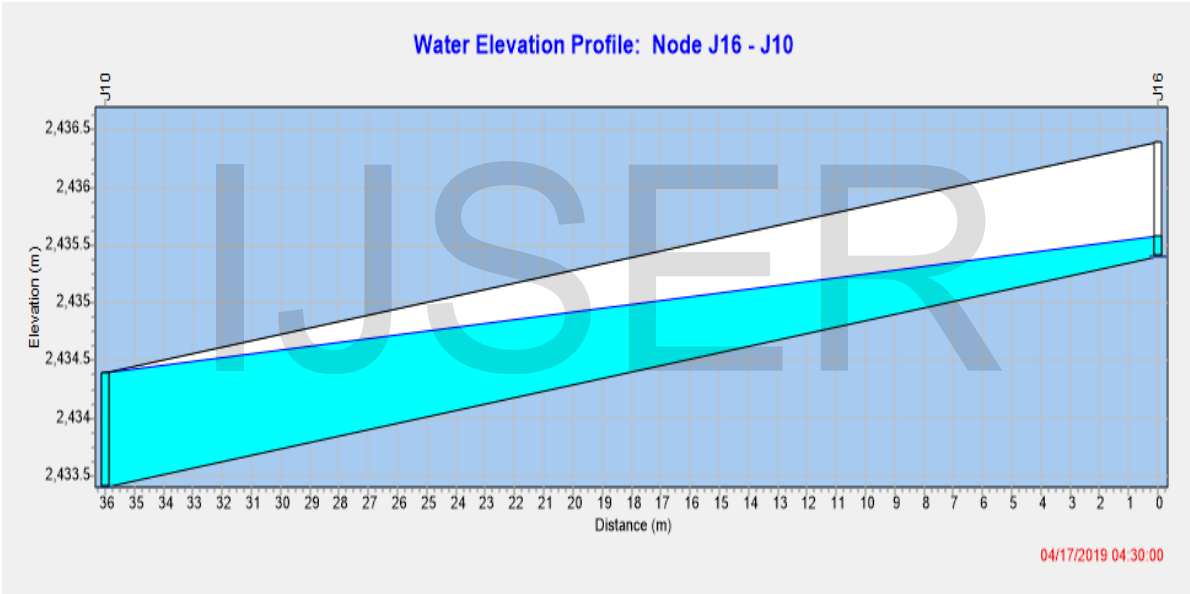


Figure 16*:* Water Elevation profile at Burka Harbu Outfall

III). Drainage towards Wajitu Outfall

The drainage canal that found an upstream part of Wajitu outfall (link C18) as the simulation result indicates Junction J12 is sufficient to carry the generated runoff and also there is no flooding as shown in figure 17. But the downstream of the link Junction J11is insufficient. That means overflow has happened in this area. That is at Wajitu Outfall the drainage canals are busy and insufficient to carry with 3hrs rainfall intensity.

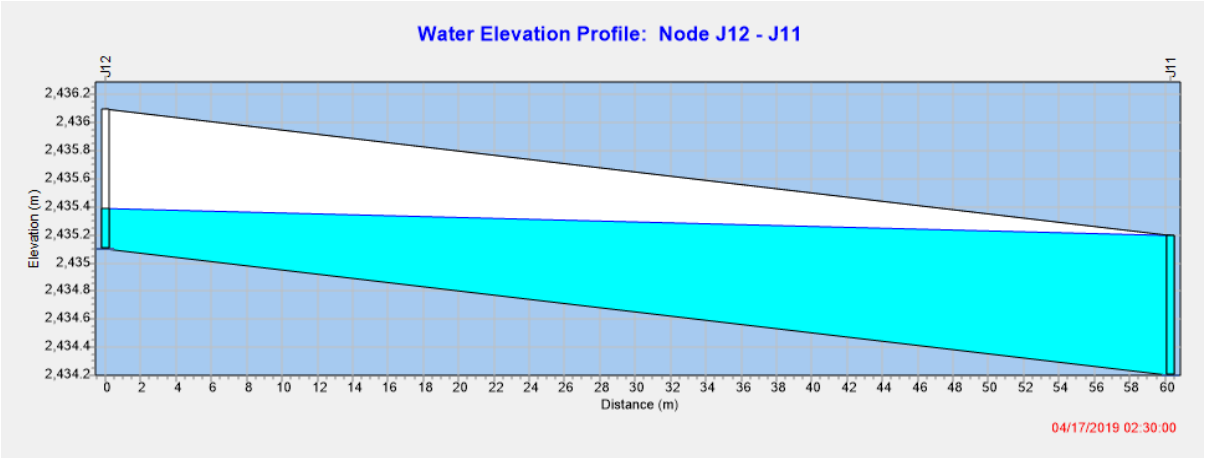


Figure 17: Water Elevation profile at Wajitu outfall

IIV). Drainage at around 44

The drainage canal that found at the upstream and downstream part of around 44 (link C8) as the simulation result indicates Junction J6 and Junction 7 is sufficient to carry the generated runoff and also there is no flooding (Fig.18).

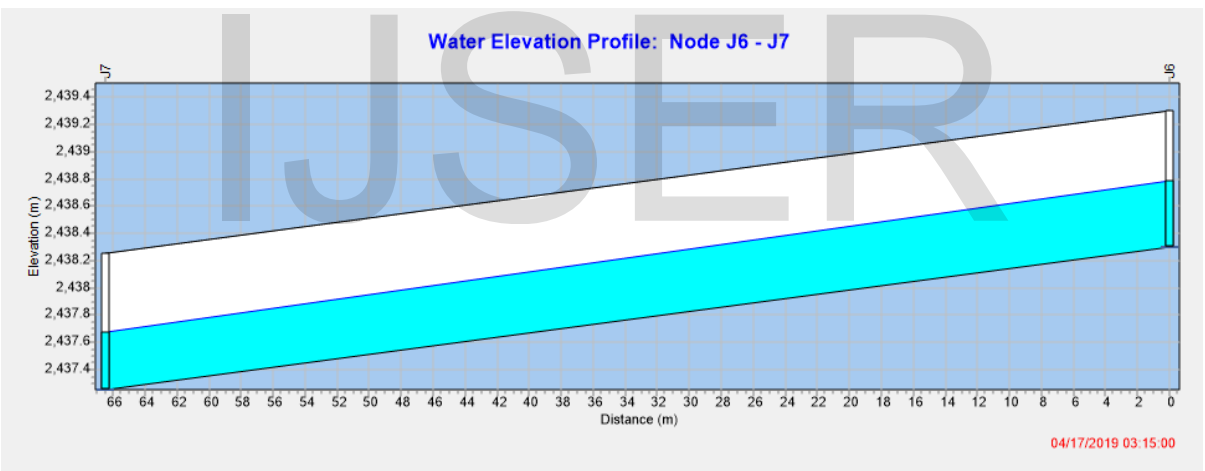


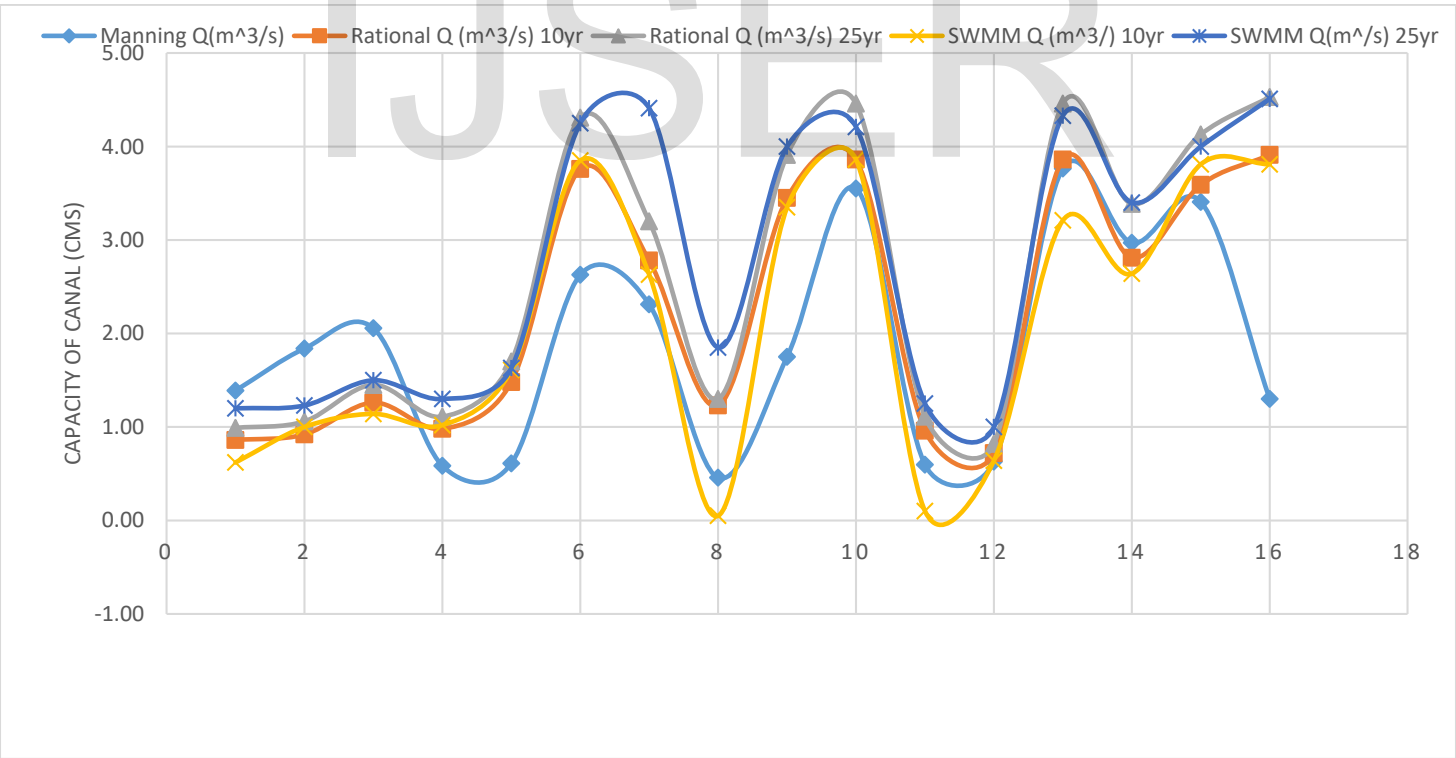
Figure 18: Water Elevation profile at around 44

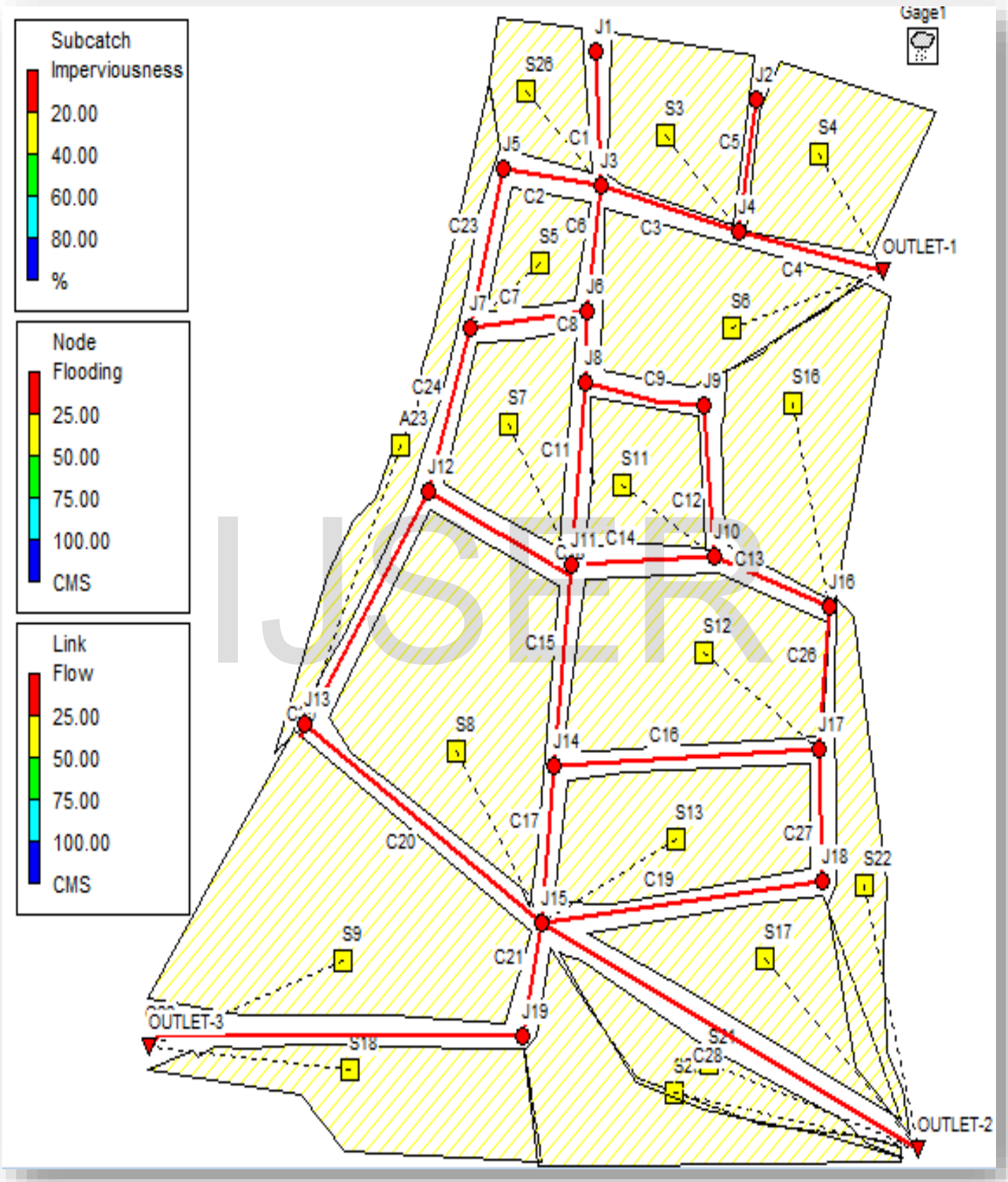
Table 2 show that, the result of discharge by SWMM 5.1 and rational method with in design period of 10 year were 36.43 and 35.34 m^3/s, were as for check 25 year were 41.927 and 44.07 m^3/s with R^2 value of 0.65 and 0.63 respectively. It show that, the performance of the SWMM Model 5.1 with Rational method was well match and acceptable in this study.

Table 2: Discharge result by rational method, SWMM and Manning Formula

Code of Sub-catch	Q (R)10Y (m^3/sec)	Q (SWMM)10Y (m^3/sec)	Q Manning (m^3/s)	Q (R)25(m^3/se)	Q (SWMM)25Y (m^3/sec)
GQsc-1	0.86	0.62	1.39	0.99	1.2

GQsc-2	0.92	0.1	1.84	1.06	1.23
GQsc-3	1.26	1.14	2.06	1.45	1.5
BHsc-1	0.98	1.02	0.59	1.11	1.3
BHsc-2	1.48	1.61	0.61	1.7	1.63
BHsc-3	3.76	3.85	2.63	4.31	4.25
WJsc-1	3.91	3.81	1.30	3.2	4.41
MGsc1	2.78	2.6	2.31	1.3	1.85
MGsc2	1.23	0.05	0.46	3.91	4
THsc1	3.45	3.35	1.75	4.46	4.21
THsc2	3.86	3.86	1.55	1.11	1.25
Ssc1	0.96	0.1	0.60	0.82	1
BWsc1	0.72	0.64	0.63	4.46	4.33
BSsc1	3.90	3.21	3.76	3.387	3.4
BSsc2	2.81	2.64	2.97	4.13	4
BSsc3	3.59	3.81	3.41	4.53	4.51




Subcatch Imperviousness
20.00
40.00
60.00
80.00
%
Node Flooding
25.00
50.00
75.00
100.00
CMS
Link Flow
25.00
50.00
75.00
100.00
CMS
Gage1
J1
J2
J3
J4
J5
J6
J7
J8
J9
J10
J11
J12
J13
J14
J15
J16
J17
J18
J19
OUTLET-1
OUTLET-2
OUTLET-3
C1
C2
C3
C4
C5
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S26
A23

5. CONCLUSIONS

- According to the result of this thesis the performance assessment of existing storm drainage systems of Holeta town were concluded that, there was no proper sewage system to collect wastes extracted from each household, as a result, solid and liquid wastes were directly disposed into the storm drainage system, lack of well-connected drainage network, which results in decreasing the efficiency of the system, unavailability of drainage systems at proper place. And the awareness of the community towards such an issue was quite poor, even those who have the awareness overwhelmed to dump wastes over the storm drainage systems because there was a lack of waste management techniques to dispose and take care of wastes. Storm drainage facility is inadequate to convey the peak discharge for the required design period and the drainage system filled by sediment and other rubbish materials. As GTZ standards more percentage of drainage systems were severely degraded.
- The study goes to assess the existing urban drainage system performance, in terms of the design storm capacity for 10 years of the return period. The main existing drainage system problem in the town was the design storm capacity, which is not as per the rainfall intensity based on the IDF curve. This result shows that there was the inadequacy of the canal capacity to cover a peak flood for the return period.
- Study evaluated the performance assessment of existing urban storm drainage systems for the case of Holeta town by using NMA data, SWMM with version 5.1, rational method used to estimate the peak flow of current runoff, Manning equation, and IDF curve for Holeta town I have developed, DEM, GIS, and different outlet and outfall points are identified in order to transport flows through the given canal dimensions.
- The result shows that the maximum flood occurs at locations High school area, Wajitu outfall, Hawi Hotel, Tulu Harbu, and Burka Harbu outfall area the most flood exposed junctions and links. However, the certain canals that actual we see the flood occurring in the town did not show the flood in the model result, this is due to the problem of management, lack of awareness of the urban solid waste disposal that leads to the closure of canal water flows. Some of the drainage canals and junction points would be malfunctioning due to siltation at manaria in front of Holeta police office cause flooding problem. Flooding at the junction points of the road from in front of municipal and water supply office is due to lack of clearance.

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