SWMM-Based Hydrological Modelling of Blue-Green Infrastructure for Climate-Resilient Stormwater Management and Urban Flood Reduction in F-North and G-North Wards of Greater Mumbai in India

Vedanti Kelkar [1,] *, Vishal Solanki [1] and Peter Krebs [1]

1. Faculty of Environmental Sciences, Institute of Urban and Industrial Water Management, Chair of Urban Water Management, TUD Dresden University of Technology, Dresden, Germany

Corresponding author: Vedanti Kelkar (Vedanti.kelkar@mailbox.tu-dresden.de)

Supplementary Materials

Thematic Mapping Using QGIS

Digital Elevation Model (DEM) can be analysed in QGIS to generate slope map, which gives necessary details of slopes in different regions. DEM has been created using the existing Ground level data available from BRIMSTOWAD II report. For further details see Appendix.

DEM requires for creating slope & contours map for both catchment in QGIS, that will be utilize as a backdrop for the tool SWMM. Model in SWMM needs % slope as input parameter for sub-catchment. Slope map generated from DEM used for classification of slope for different area of the catchment. Model in SWMM needs invert levels to be compute for link/conduits that completely depends on pattern of soil strata and ground elevations of particular area. In storm water drainage system, network is prepared in such a way that flow to be take place in the system refers elevation difference. Therefore, to create that type of arrangement, proper gradient of storm water drainage system is required which needs proper evaluation of invert levels of drainage networks. **Figure S1** and **Figure S2** show the Digital Elevation Models (DEMs) of Catchment 506&507 and Catchment 410, respectively, highlighting the topographic variation across both drainage areas.

In order to assist with hydrological analysis and model development, a slope map was created using the DEM in the QGIS environment. The DEM was analysed using the "Slope" function within the raster Terrain Analysis toolbox. This function is able to determine the rate of change in the elevation of each pixel by analysing properties of the surrounding cells thereby examining the steepness of the terrain. The output slope layer was generated, and was continuous across the raster to delineate the topographic variation across the study area. Steeper slopes generally reflect a faster ability to runoff water, while flatter areas are expected to experience some drainage or water accumulation/infiltration. The slope map was then used to assist with sub catchment delineation and provide hydrological characteristics to various drainage units in the SWMM model. **Figure S3** and **Figure S4** present the slope maps of Catchment 506&507 and Catchment 410, respectively, derived from the DEM, and used to assess terrain steepness and flow direction across the study area.

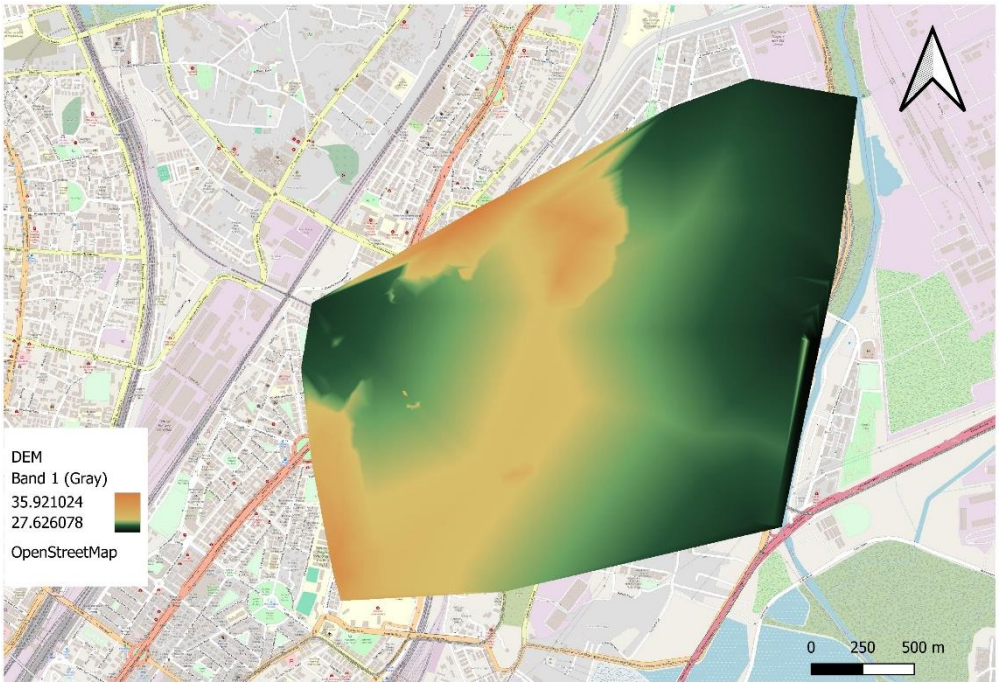


Figure S1: DEM of Catchment 506&507

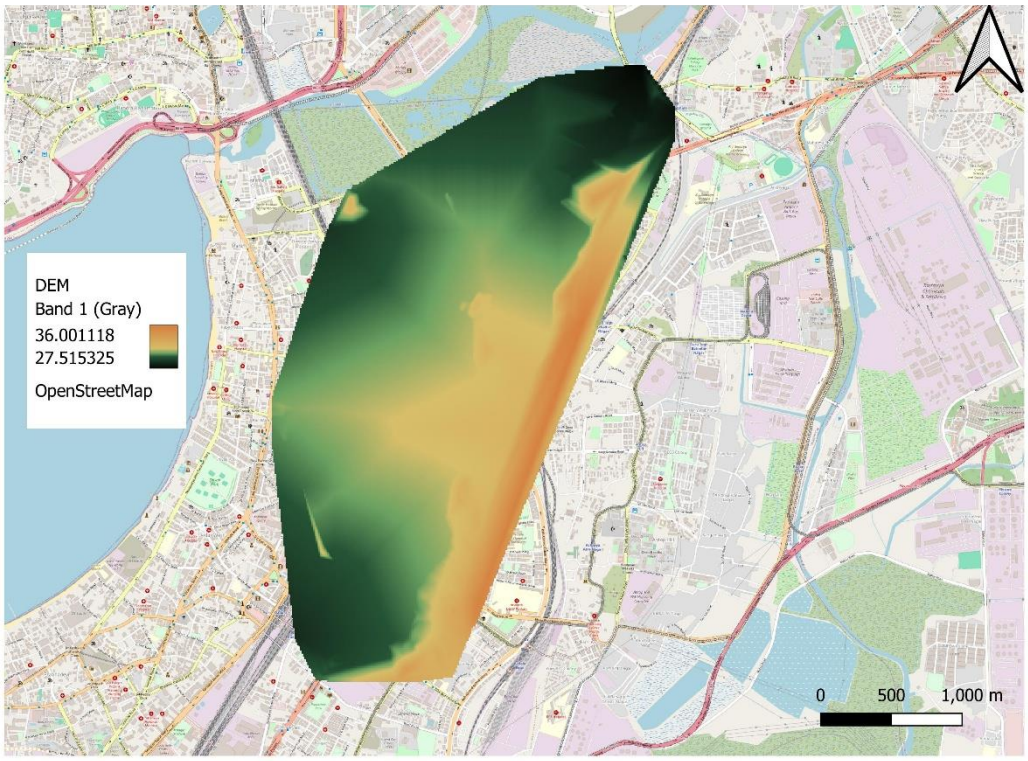


Figure S2: DEM of Catchment 410

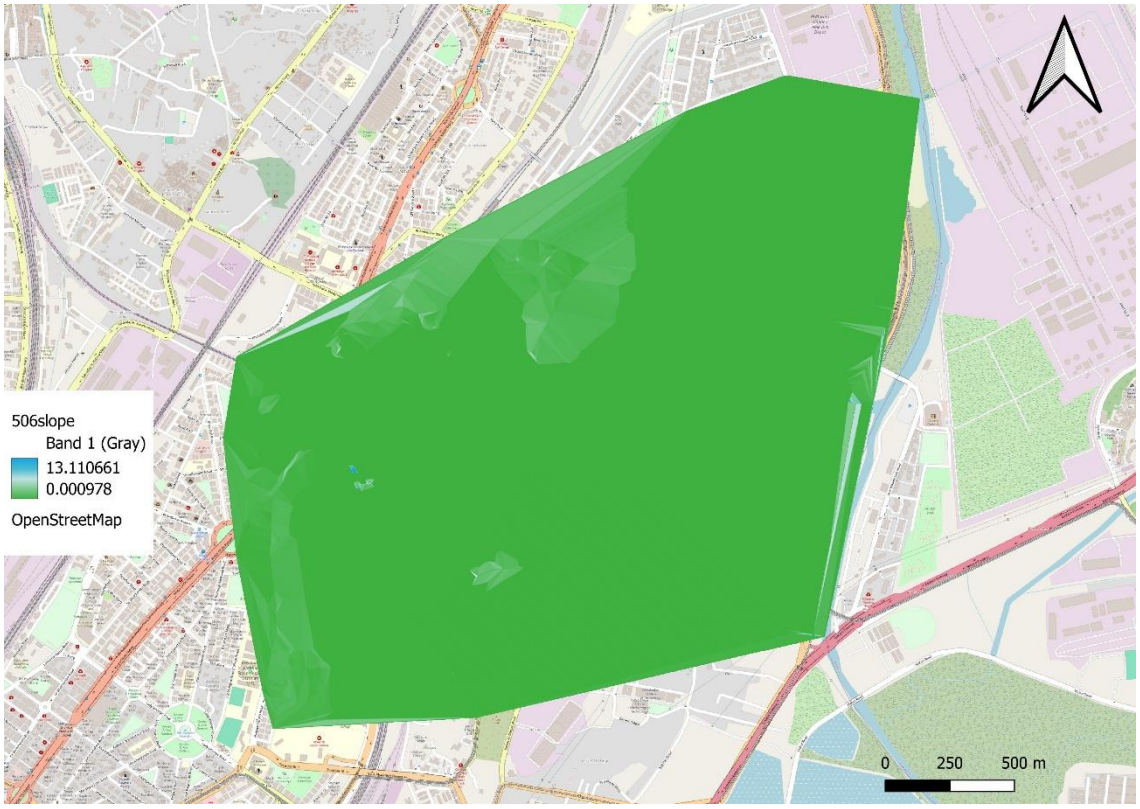


Figure S3: Slope map of catchment 506&507

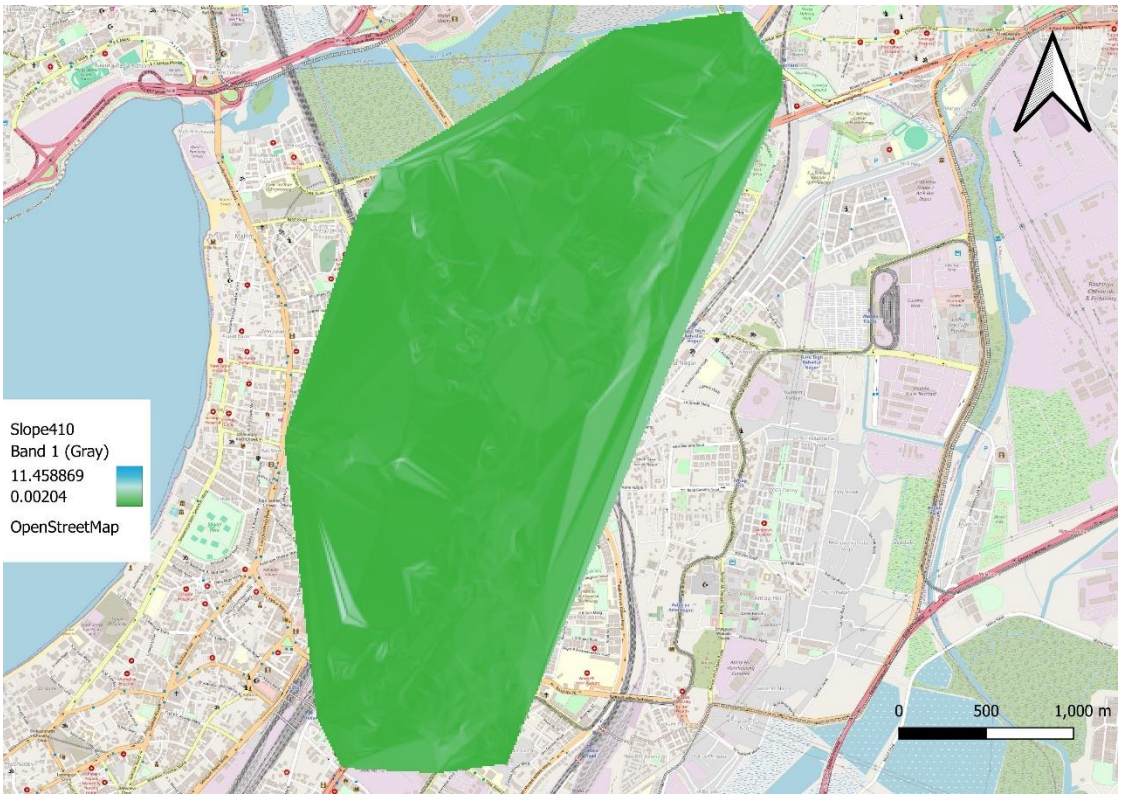


Figure S4: Slope map of catchment 410

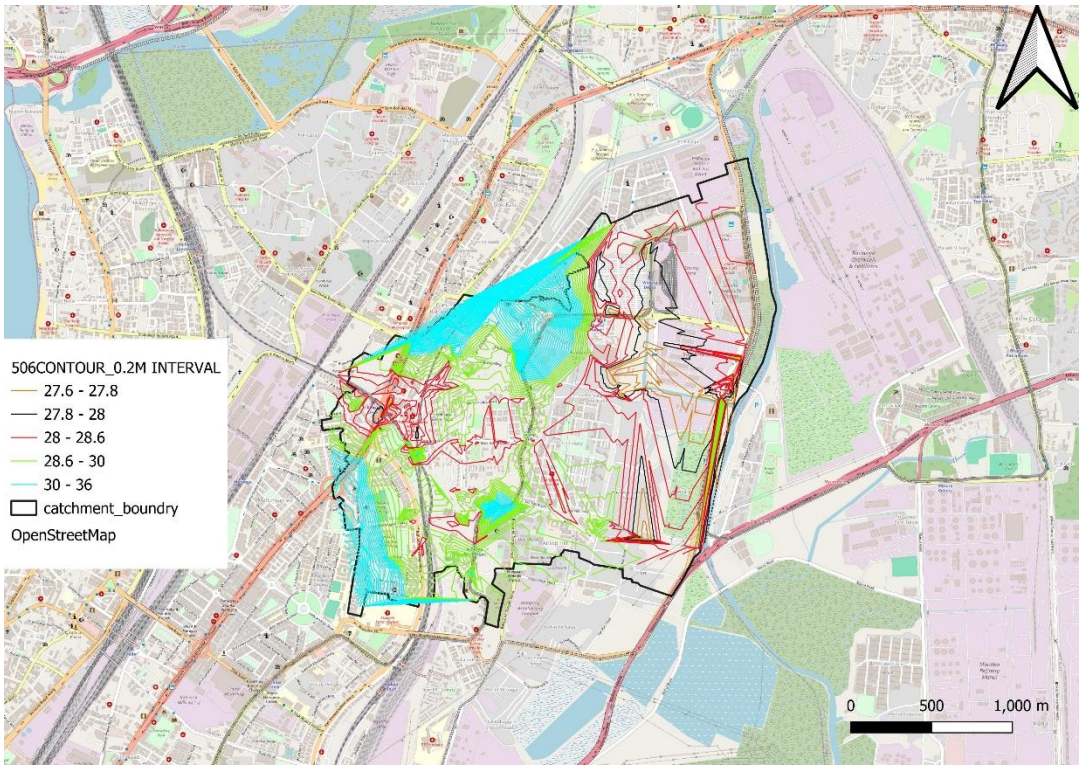


Figure S5: Contour of Catchment 506&507

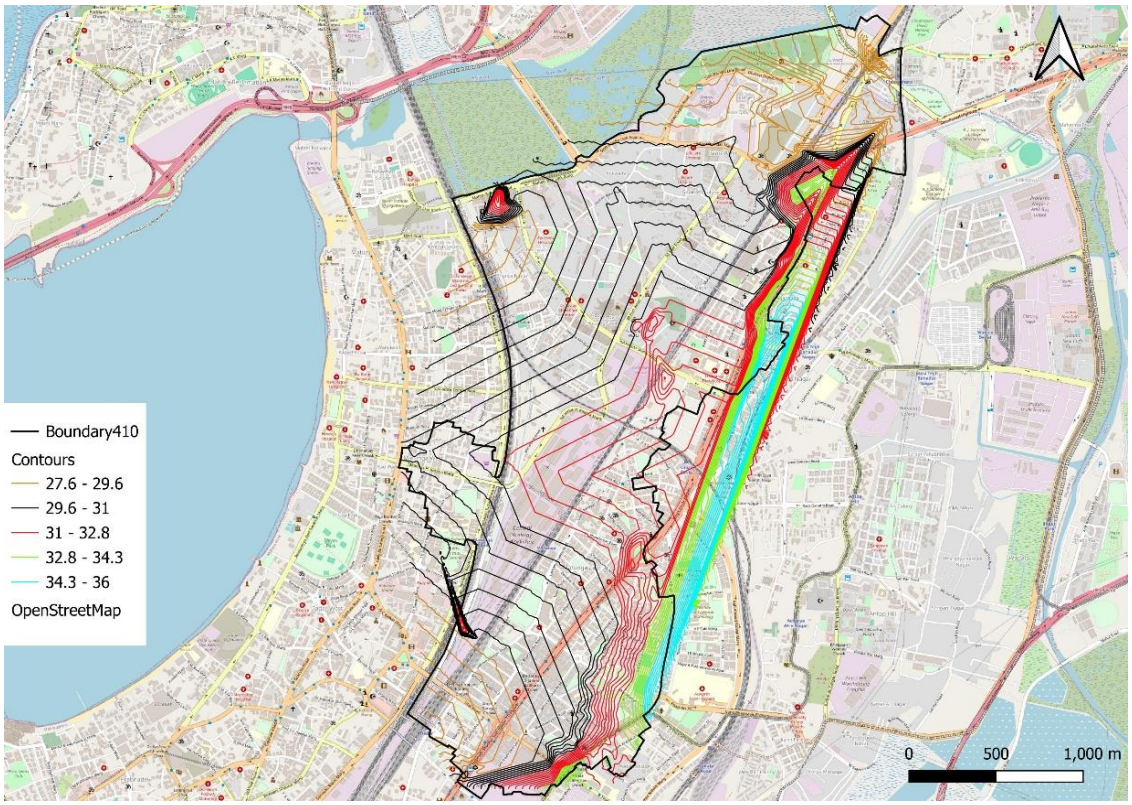


Figure S6: Contour of Catchment 410

Development of Storm water drainage model using SWMM

Importing Nodes, Links and Outfall in SWMM

As part of the model development process, the geometric and hydraulic characteristics of the existing storm water drainage network such as conduit dimensions, cross-sectional shapes, ground elevations, and invert levels were first compiled and organized in a structured Excel format. These parameters are essential for accurately representing the physical behaviour of the drainage system within the simulation environment. The compiled data were then formatted to meet the input structure required by the EPA Storm Water Management Model (S WMM), which utilizes a text-based. inp (input) file for model execution.

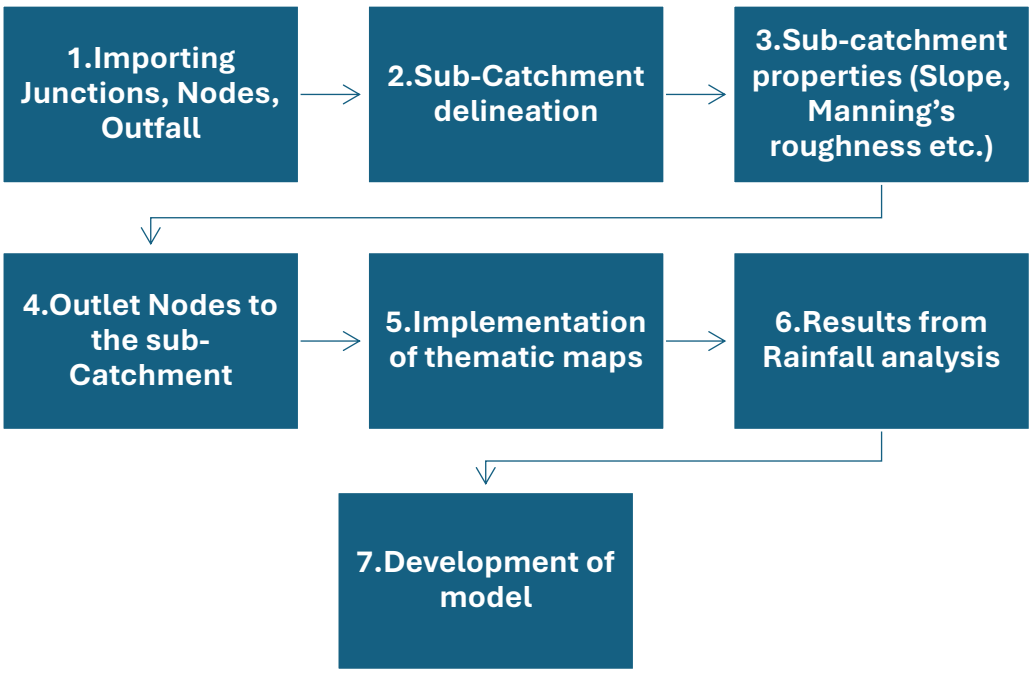


Figure S7: Flow Chart of Methodology for SWMM development

To facilitate this, **Notepad++,** an editor compatible with SWMM's input file format, was used for data entry and editing. Notepad++ allows efficient handling of structured text and is particularly useful for managing large datasets typical of urban drainage models. Using this tool, various components of the storm water network including Junctions.

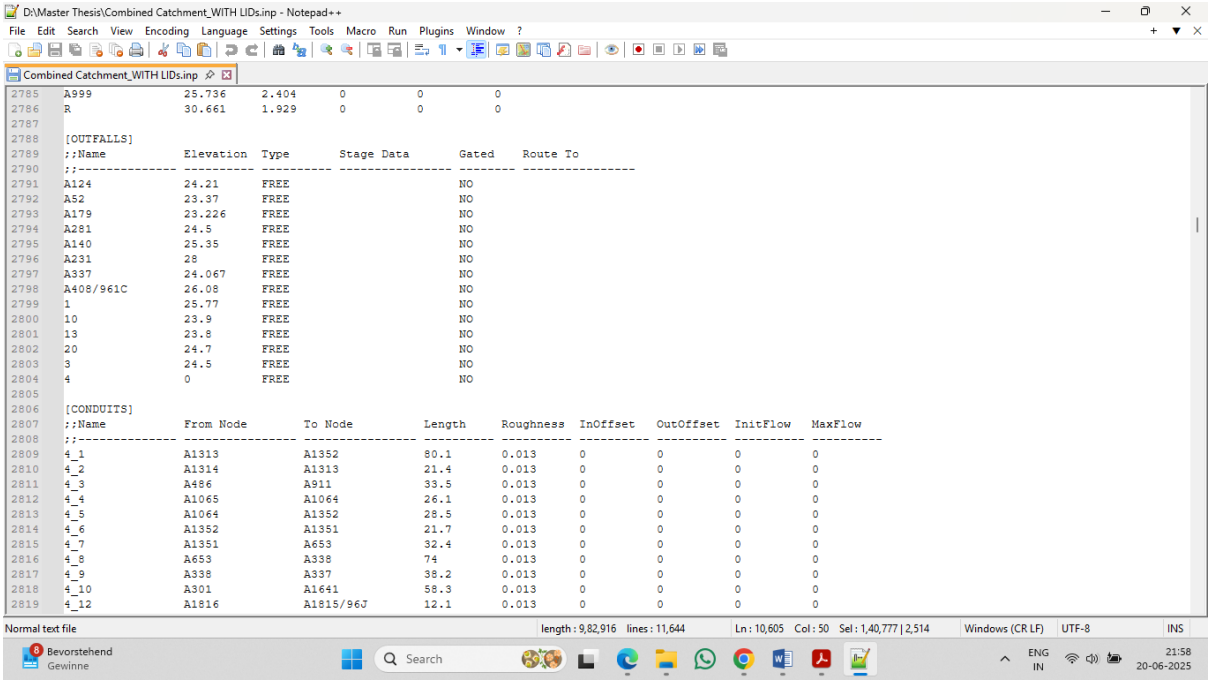


Figure S8: Notepad++ window for SWMM input

Links (Conduits), Sub-catchments, and Outfalls were manually encoded in the appropriate syntax defined by SWMM. This process ensured that the drainage database accurately reflected the existing field conditions and could be successfully interpreted by the SWMM simulation engine. The prepared input file was subsequently validated within SWMM to confirm data integrity and model readiness for hydrologic and hydraulic simulation.

Sub-catchment delineation

Sub-catchment delineation was carried out to divide the study area into hydrologically homogeneous units for accurate runoff simulation. Each sub-catchment was defined based on topography, drainage flow direction, land use, and surface characteristics. Parameters such as area, slope, width, percent imperviousness, and depression storage were assigned to reflect local conditions (See **Figure S9**). The delineation ensured proper representation of flow contribution to the storm water network within the SWMM model.

The delineation of the both catchment area was carried out by analysing the natural flow direction derived using the "Watershed" tool available in QGIS (See **Figure S10** and **S11**). This tool utilizes hydrologically corrected Digital Elevation Models (DEMs) to determine the drainage patterns and flow accumulation paths across the terrain. Sub catchments were delineated based on topographic features, slope gradients, and flow direction to accurately define the contributing area for surface runoff generation.

process involved overlaying the slope map and stream network generated from the DEM to identify natural drainage paths and the most probable outlet points. These outlet points represent the lowest elevation within each sub catchment and serve as logical locations for assigning runoff-receiving junctions or nodes within the SWMM hydraulic model. The derived stream direction layer (**Figure S10** and S11) was particularly useful in understanding the hydrological behavior of the terrain, ensuring that sub catchment boundaries aligned with natural water flow. This topography-driven delineation

enhances the spatial accuracy of runoff routing and ensures realistic simulation of storm water flow within the model domain.

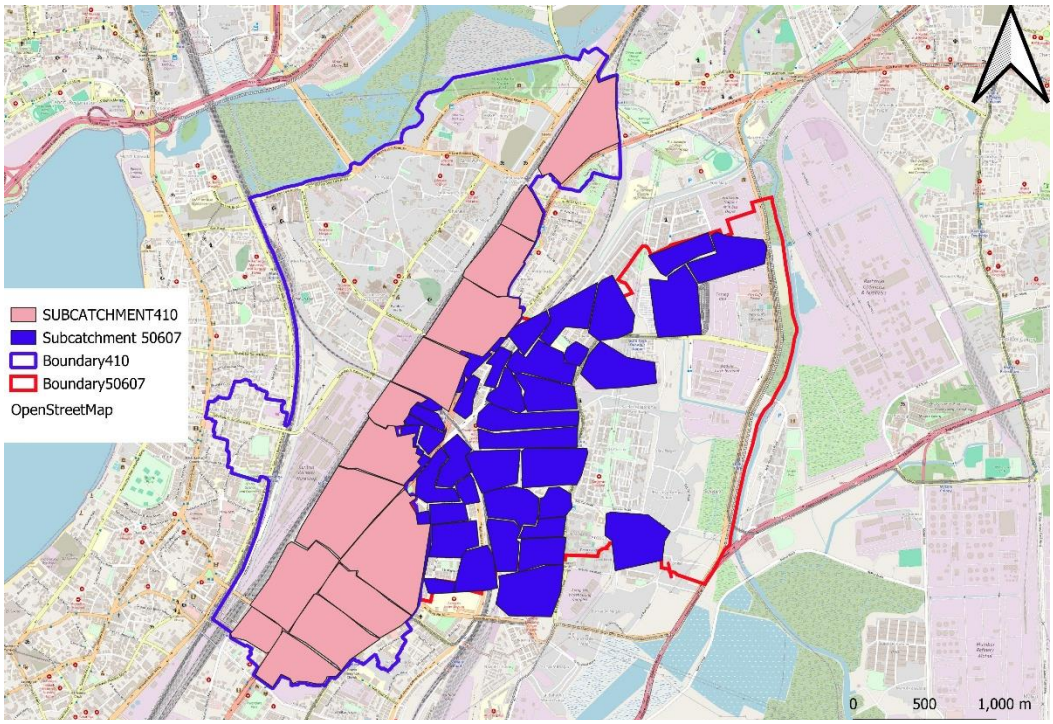


Figure S9: Sub Catchment delineation

y

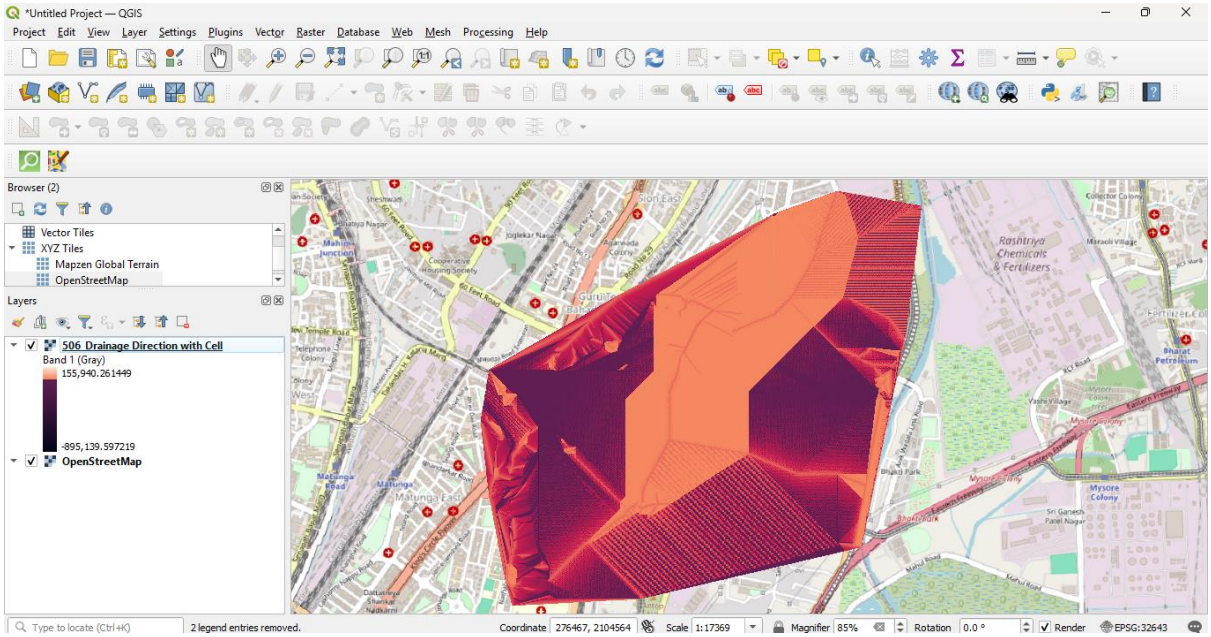


Figure S10: Stream direction for Catchment 506 507

The next critical step in the model development process involves quantifying the total impervious area within the delineated catchment. Given that both Ward F/N and Ward G/N are densely urbanized and highly developed, assessing the distribution of surfaces is impervious versus pervious essential for accurate runoff estimation. To obtain this information, data from OpenStreetMap (OSM) an open-source geospatial database was utilized. OSM provided comprehensive vector data layers, including buildings, roads, industrial zones, educational institutions, and government properties, which are key indicators of impervious surfaces.

Using the “Clip” tool in QGIS, features located outside the administrative boundaries of the study area were excluded to retain only relevant spatial data. Subsequently, the “Intersection” tool was applied to overlay the filtered building footprint layer with the previously delineated sub catchment boundaries. This allowed for precise spatial association of impervious features within each sub catchment.

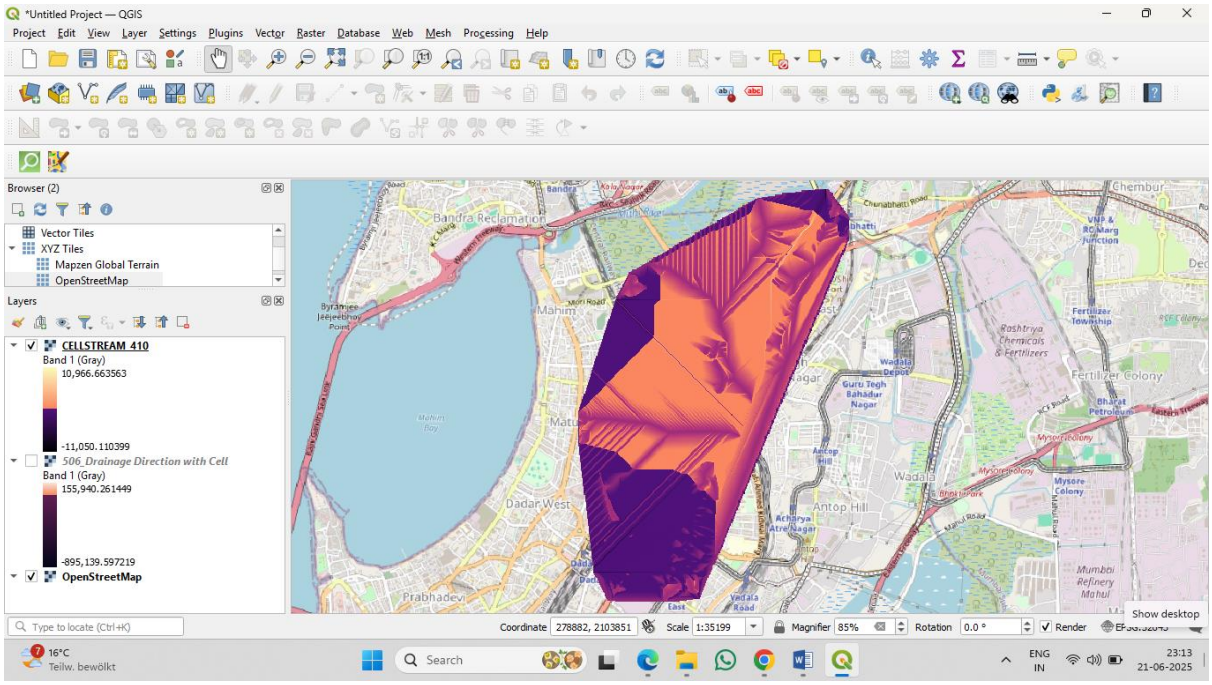


Figure S11: Stream direction for Catchment 410

To further enhance the spatial detail, the “Zonal Statistics” tool was employed to compute slope characteristics for each sub catchment by linking the slope raster (derived from the DEM) to the vector-based sub catchment layer. This tool enabled extraction of statistical information such as mean slope and percent imperviousness, which are critical input parameters for sub catchment configuration in SWMM.

The final step in this process involved identifying the outlet point for each sub catchment, which represents the location where runoff exits and enters the drainage network. For this, the “Select by Attribute” tool was used in combination with the Digital Elevation Model (DEM) and the junction node layer. The tool facilitated the selection of the nearest downstream node relative to each sub catchment's lowest elevation point, ensuring accurate flow routing in the hydraulic model. This integrated GIS-based approach allowed for efficient pre-processing and spatial attribution of key sub catchment parameters necessary for SWMM simulation.

The process of creating contour lines was used, within the scope of the project, to understand the terrain features at the study site, and for use in hydrological model inputs. The contour lines have been created by using the contour tool with a raster data set. As a first step, or preparation, the DEM data set had already been imported into QGIS as the base data for the elevation-based analysis. The contour tool from the Processing Toolbox was used to extract contour lines. The DEM was specified as the input layer, and to set an appropriate contour interval (1 or 5 m) again would be based on the shifting topography and resolution of the DEM that would affect contour accuracy. The output was also set to include an elevation attribute for each of the contour lines. When the tool executed, the output was a vector layer of contour lines for the contours at the study catchment, to show the gradient in elevation across the catchment study area. This vector was then used as for use as a study layer in other spatial analysis, slope, delineating sub catchments, flow directions, and the contours layer also provided

important topographic data for use in setting up and calibrating the SWMM model. **Figure S3** and **Figure S4** display the contour maps of Catchment 506/507 and Catchment 410, respectively, generated from the DEM to represent elevation variations and support topographic analysis within the study area.

Table S1: Table showing the areas of proposed BGI interventions in this study

Subcatchment ID	LID	Number	Area	Width	Init Sat	From Imp	To Perv
410_1	PP	3	1270	2	10	20	0
410_1	IT	1	180	3	25	25	0
410_2	PP	3	4385	2.5	30	20	0
410_3	PP	3	2461	2	30	50	0
410_3	IT	10	234	0.5	25	30	0
410_4	PP	1	5094	1.5	30	50	0
410_4	IT	1	2073	4	25	30	0
410_5	PP	1	253	1.5	30	25	0
410_5	IT	1	357	1	30	20	0
410_6	PP	1	5769	2	30	40	0
410_8	PP	1	5679	2	20	25	0
410_8	IT	1	333	0.5	25	5	0
410_9	PP	3	581	1.5	30	50	0
410_9	IT	1	116	2	25	30	0
410_10	PP	1	2387	1.5	10	60	0
410_12	GR	1	9637	30	10	30	0
410_13	GR	1	558	30	10	15	0
506_1	PP	3	506	1.5	30	50	0
506_30	GR	1	660	30	10	30	0
506_39	GR	1	1449	18	10	15	0
506_40	GR	1	1847	30	10	30	0
506_42	GR	3	717	30	10	15	0
506_57	GR	1	1038	60	10	30	0

Table S2: Time-Interval Rainfall Intensities Used for SWMM Simulation

Sr No	Interval (min)	25 Year (mm/hr)	10 Year (mm/hr)	5 Year (mm/hr)	2 Year (mm/hr)
1	10	227.73	201.02	179.89	147.96
2	20	170.80	150.77	134.91	110.97
3	30	132.84	117.26	104.93	86.31
4	40	106.28	93.81	83.95	69.05
5	50	86.95	76.75	68.68	56.49
6	60	72.46	63.96	57.24	47.08
7	70	61.31	54.12	48.43	39.83
8	80	52.55	46.39	41.51	34.14
9	90	45.55	40.21	35.98	29.59
10	100	39.85	35.18	31.48	25.89
11	110	35.17	31.04	27.78	22.85
12	120	31.26	27.59	24.69	20.31
13	130	27.97	24.69	22.09	18.17
14	140	25.17	22.22	19.88	16.35
15	150	22.77	20.10	17.99	14.80
16	160	20.70	18.28	16.35	13.45
17	170	18.90	16.69	14.93	12.28
18	180	17.33	15.30	13.69	11.26
19	190	16.63	14.68	13.14	10.81
20	200	14.72	12.99	11.62	9.56

Sr No	Interval (min)	25 Year (mm/hr)	10 Year (mm/hr)	5 Year (mm/hr)	2 Year (mm/hr)
21	210	13.63	12.03	10.76	8.85
22	220	12.65	11.17	9.99	8.22
23	230	11.78	10.40	9.30	7.65
24	240	10.99	9.71	8.68	7.14
25	250	10.29	9.08	8.12	6.68

Table S3: Table showing Pre and Post Flooding Nodes

Node	Hour Flooded	Max Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood volume 10^6 ltr	Maximum ponded depth Meteres
1082	1.99	1210.25	0	00:20	4.355	0
197	1.67	1557.87	0	00:20	4.621	0
A1052/29J	1.54	5527.98	0	00:49	17.801	0
148	1.51	1203.79	0	00:20	3.418	0
900	1.24	1104.44	0	00:30	2.729	0
A153	1.23	318.1	0	00:49	1.004	0
A624	1.13	109.44	0	00:40	0.423	0
869	1.11	1412.55	0	00:20	3.1	0
613	1.08	917.41	0	00:20	1.956	0
A623/46C	1.08	376.42	0	00:30	1.159	0
868	1.05	80.12	0	00:22	0.189	0
A1938/44J	0.98	1734.82	0	00:20	3.597	0
A115	0.97	148.7	0	00:17	0.403	0
511/52H	0.89	345.98	0	00:40	0.655	0
133	0.86	345.77	0	00:20	0.644	0
620	0.75	416.81	0	00:10	0.639	0
18539	0.73	2169.09	0	00:30	3.556	0
851/8J	0.66	1107.53	0	00:21	1.173	0
A1611/189J	0.64	1200.77	0	00:22	1.676	0
A97	0.6	72.99	0	00:16	0.016	0
A90	0.55	129.3	0	00:15	0.04	0
A158	0.39	45.6	0	00:56	0.035	0
377	0.38	10.07	0	00:31	0.012	0
556/48H	0.37	211.98	0	00:20	0.101	0
252	0.37	49.14	0	00:30	0.028	0
461	0.35	70.01	0	00:31	0.052	0
A1585	0.26	224.7	0	02:21	0.056	0

506/53H	0.15	83.55	0	00:18	0.017	0
A100	0.09	218.26	0	00:14	0.003	0
A1728/26J	0.08	579.7	0	00:56	0.063	0
924	0.02	205.5	0	00:06	0.008	0
159	0.01	62.46	0	00:03	0	0
619	0.01	113.01	0	00:11	0	0
919	0.01	166.48	0	00:05	0	0
920	0.01	4.08	0	00:06	0	0
508/57H	0.01	204.99	0	00:11	0.001	0
849	0.01	95.06	0	00:03	0	0
90	0.01	22.17	0	00:16	0	0
609	0.01	26.39	0	01:18	0	0
610	0.01	12.25	0	00:05	0	0
886	0.01	81.17	0	00:14	0	0
897	0.01	8.15	0	00:06	0	0
100	0.01	14.38	0	00:13	0	0
A1320/55H	0.01	60.66	0	00:12	0	0
160	0.01	33.92	0	00:11	0	0
921	0.01	1.8	0	00:06	0	0
923	0.01	184.58	0	00:05	0	0
861	0.01	90.09	0	00:03	0	0
161	0.01	116.73	0	00:03	0	0
848	0.01	85.34	0	00:03	0	0
A1047	0.01	15.05	0	00:13	0	0
153	0.01	14.43	0	00:03	0	0
A1073/47J	0.01	261.27	0	00:12	0.002	0
A1100	0.01	21.47	0	00:35	0	0
18535	0.01	3.36	0	00:18	0	0
925	0.01	287.32	0	00:06	0.001	0
157	0.01	232.3	0	00:03	0	0
6844	0.01	60.59	0	00:13	0	0
18533	0.01	56.73	0	00:18	0.001	0
A1041	0.01	949.93	0	00:14	0.001	0
230	0.01	5.65	0	00:19	0	0
219	0.01	33.85	0	00:19	0	0
162	0.01	92.45	0	00:04	0	0
5/56J	0.01	446.59	0	00:13	0	0
A1101	0.01	11.03	0	00:35	0	0
881/41H	0.01	267.76	0	00:07	0.002	0
906/111H	0.01	45.92	0	00:09	0	0
A10	0.01	258.76	0	00:13	0	0
A1107/73J	0.01	714.23	0	00:11	0.001	0
A1108	0.01	17.72	0	00:17	0	0
A1117	0.01	52.68	0	00:11	0	0
A1147	0.01	121.89	0	01:57	0	0
A1102	0.01	93.88	0	02:07	0.001	0
A114	0.01	71.24	0	00:17	0	0
A1145	0.01	12.46	0	00:16	0	0

A1146	0.01	28.16	0	00:16	0	0
A1118	0.01	46.38	0	00:12	0	0
464	0.01	20.43	0	00:16	0	0
A1171	0.01	67.06	0	00:45	0	0
A1175	0.01	46.45	0	00:17	0	0
A1176	0.01	28.18	0	00:18	0	0
120	0.01	143.25	0	00:05	0	0
A1180	0.01	3.54	0	00:45	0	0
A1188	0.01	5.79	0	00:36	0	0
A1200	0.01	0.29	0	00:28	0	0
A1201	0.01	48.69	0	00:28	0	0
A1137	0.01	12.86	0	00:09	0	0
A1235	0.01	27.09	0	00:14	0	0
A1281	0.01	14.08	0	00:08	0	0
A1398	0.01	18.85	0	00:45	0	0
A1451/61J	0.01	546.41	0	00:21	0.001	0
A1234	0.01	27.53	0	00:14	0	0
A1324	0.01	238.49	0	02:06	0.003	0
A1397	0.01	13.73	0	00:45	0	0
A1282/75J	0.01	451.56	0	00:11	0.001	0
A1520/78J	0.01	404.11	0	00:17	0	0
462	0.01	6.35	0	00:16	0	0
447	0.01	355.29	0	01:51	0.005	0
376	0.01	45.85	0	00:08	0	0
A1228	0.01	57.19	0	00:14	0	0
A1419/71J	0.01	1171.6	0	00:12	0.001	0
A1490	0.01	18.6	0	00:14	0	0
A1514	0.01	150.51	0	00:18	0	0
A152/57H	0.01	98.83	0	00:12	0	0
A1442	0.01	430.07	0	00:14	0.002	0
A1577	0.01	28.56	0	00:29	0	0
A1578	0.01	29.2	0	00:29	0	0
A1521	0.01	23.32	0	00:17	0	0
A217	0.01	4.03	0	00:41	0	0
A1778	0.01	40.29	0	00:15	0	0
A157	0.01	12.41	0	00:36	0	0
A1540/69J	0.01	958.26	0	00:12	0.002	0
A1770	0.01	118.96	0	02:34	0	0
A1633	0.01	496.82	0	00:13	0	0
A1656	0.01	371.41	0	02:18	0.005	0
A1547/76J	0.01	125.98	0	00:15	0	0
A1661	0.01	137.55	0	00:18	0.001	0
A1671	0.01	94.32	0	00:14	0	0
A1850	0.01	212.11	0	00:14	0.001	0
A1859/150J	0.01	424.04	0	00:12	0	0
A180	0.01	14.63	0	00:44	0	0
A828/77J	0.01	1087.61	0	00:11	0.002	0
A841	0.01	4.49	0	00:13	0	0

A1849	0.01	94.95	0	00:14	0	0
A1819/163J	0.01	2679.92	0	00:14	0.004	0
A229/58H	0.01	29.48	0	00:14	0	0
A192	0.01	138.92	0	00:17	0	0
A206/84J	0.01	512.84	0	00:12	0	0
A1827	0.01	67.61	0	00:14	0	0
A220	0.01	33.4	0	00:43	0	0
A222	0.01	10.24	0	00:46	0	0
A275	0.01	69.57	0	00:10	0	0
A23	0.01	131.01	0	00:18	0	0
A243	0.01	492.06	0	00:16	0.001	0
A33	0.01	112.45	0	00:16	0.001	0
A261	0.01	65.98	0	00:15	0	0
A262	0.01	31.66	0	00:33	0	0
A249	0.01	15.13	0	00:37	0	0
A278	0.01	41.52	0	00:32	0	0
A279	0.01	50.41	0	00:32	0	0
A284	0.01	123.19	0	00:17	0	0
A30	0.01	72.18	0	00:13	0.001	0
A305	0.01	8.7	0	00:19	0	0
A317	0.01	43.25	0	00:12	0	0
A40	0.01	112.77	0	00:13	0.001	0
A346	0.01	562.34	0	00:16	0	0
A348/49J	0.01	238.98	0	00:13	0.001	0
A1660	0.01	126.24	0	00:18	0	0
A369	0.01	10.89	0	00:32	0	0
A372	0.01	64.02	0	00:34	0	0
A352/85H	0.01	145.91	0	00:15	0.001	0
A426	0.01	244.91	0	00:16	0	0
A433	0.01	45.69	0	00:28	0	0
A440	0.01	22.07	0	00:12	0	0
A441	0.01	31.85	0	00:12	0	0
A445	0.01	4.62	0	00:55	0	0
A453	0.01	36.73	0	00:13	0	0
A816	0.01	94.6	0	00:14	0	0
A68	0.01	119.54	0	01:54	0.001	0
A553	0.01	405.35	0	00:13	0.001	0
A491	0.01	127.58	0	00:09	0	0
A715/151J	0.01	379.89	0	00:15	0	0
A657/48J	0.01	92.51	0	00:12	0	0
A66	0.01	92.36	0	00:09	0	0
A496	0.01	912.12	0	00:16	0.002	0
A479	0.01	382.33	0	00:17	0	0
A517/45J	0.01	231.94	0	00:12	0	0
A55	0.01	15.19	0	00:36	0	0
A497/165J	0.01	512.29	0	00:16	0.003	0
A474	0.01	20.96	0	00:16	0	0
A478	0.01	51.84	0	00:15	0	0

18540	0.01	574.01	0	00:14	0.001	0
154	0.01	8.56	0	00:03	0	0
A608	0.01	82.63	0	00:11	0	0
504/54J	0.01	292.41	0	00:18	0	0
818/7J	0.01	34.49	0	00:14	0	0
18541	0.01	28.08	0	00:14	0	0
A625	0.01	12.02	0	00:15	0	0
A587	0.01	1155.93	0	00:16	0.002	0
A695	0.01	17.43	0	00:19	0	0
A701	0.01	67.97	0	00:12	0	0
A647	0.01	29.58	0	00:13	0	0
A559	0.01	40.34	0	00:24	0	0
A571	0.01	48.49	0	00:16	0	0
A914	0.01	0.35	0	00:18	0	0
A764	0.01	6.19	0	00:36	0	0
A773	0.01	12.41	0	00:35	0	0
A949	0.01	27.79	0	00:17	0	0
A952	0.01	158.33	0	00:19	0	0
A954	0.01	287.84	0	00:14	0	0
A814	0.01	269.63	0	00:13	0	0
A86	0.01	43.16	0	00:19	0	0
A87	0.01	45.24	0	00:34	0	0
A908	0.01	30.95	0	00:13	0	0
A733	0.01	35.65	0	00:13	0	0
A742	0.01	15.68	0	00:33	0	0
A758	0.01	45.56	0	00:11	0	0
A504	0.01	97.45	0	00:20	0	0
A934	0.01	5.6	0	00:12	0	0
A935	0.01	70.29	0	00:12	0	0
A550	0.01	50.44	0	00:12	0	0
A500	0.01	16.22	0	00:38	0	0
A503	0.01	55.87	0	00:19	0	0
A948	0.01	7.34	0	00:17	0	0
A955	0.01	9.39	0	00:17	0	0
A972	0.01	269.78	0	00:14	0.001	0
A98	0.01	372.63	0	00:13	0.001	0
A915	0.01	23.2	0	00:18	0	0
A924	0.01	7.09	0	00:38	0	0
A925	0.01	9.23	0	00:35	0	0