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Research Paper

Integrative Approach for Designingthe Collection SystemNetwork for Malappuram City, Kerala using MIKE+ Model

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ABSTRACT

MIKE+ model is used to design the collection system of Malappuram city situated at 54 km south west of Calicut and 90 km North West of Palakkad of Kerala state. The shapefile of the study area, SRTM 30m Digital Elevation Model, and rainfall data for the years 2017-2020 were collected and added as layers in MIKE+. Through manhole digitization followed by link creation, catchment delineation, catchment connection, and various boundary conditions, the rainfall-runoff model and catchment discharge by rational formula were determined. In Malappuram city, there are nine outlets, majority of sewers are delivering water to outlets at nodes 1156, 2344, and 2955 to reduce the burden of waste. According to the diameter of the manholes, the collection system was observed to be overdesigned, but it is capable of collecting all wastewater from each residence and catchment runoff to outlets without the need of pumps by gravity flow. In future perspective, if the water level exceeds the set critical level, mainly for the trunks sewer A and G, it will be a point of concern and requires attention.

Keywords: MIKE+; 1-D Pipe hydrodynamics; Time area Method; Manhole digitization.

INTRODUCTION

Existing water resources are being strained as a result of rapid urbanization. Because of both ongoing urban development and climate change; the worldwide movement towards SUDS not only enhances the urgent environment by blue-green space construction but also provides some kind of possible security and should be recognized as an important adaptation change (Annette, et al., 2008). The water source for drinking and collection system network for collecting dry weather flow and wet weather flow is not only fundamental human needs, but they are also vital to achieving the goal of health for all and environmental protection has been the most important in the new era of sustainable development. As a consequence of unchecked urban development, contamination of drinking water sources by sewage has posed a major public health and welfare danger. Sewage is a broad term that includes domestic and industrial wastewater and stormwater runoff, gulley melting and catching bodies from urban surfaces. Increased per capita water demand and other causes, along with improvements to land use, triggered population changes, living conditions, per capita water supply, and the quality of the sewage discharge. The sewage system's deficiency, the inappropriate design of the sewage system and its long-term failure make the frame unqualified for coping with the listed elements.

The appropriate drainage system involves wastewater collection from a source into a sewer pipe, processing by using the available cost-effective technique following specified disposal requirements, and responsible disposal in natural water bodies. There are two types of sewerage system: 1) Dry system (conservancy system) 2) Wet system (water transported system). In general, there are two methods for collecting and disposing of wastewater: (i) Separate sewerage system – Dry weather flow and stormwater are independently collected and water is treated for safe discharge and (ii) Combined system – Dry weather flow and stormwater are collected and processed together in the same pipe. The separate scheme is now preferred because of its technological and economic advantages. Therefore, nearly all of the sewer networks in India are now designed for separate systems. There are no adequate sewage systems for around 80 per cent of India's population (National Family Survey -3: 2005 - 2006). Around 55% of rural households and around 12.6% of urban households defecate in the open. In slums, this is higher as 18.9 percent of households go outside (Data tabled in the Lok Sabha on May 7, 2015). According to a 2011 survey it is also noted that, under the Swatch Bharat Mission, about 8 million of the 4,041 Indian Statutory towns have not had access to toilets and remain free to defecate. In rural areas, almost 69 per cent of India's population lacks sanitation facilities. This demonstrates the pathetic condition in rural and urban areas in terms of their basic sanitation requirements. The two-thirds urban community does not have adequate wastewater facilities, so rural people are nearly away from the wastewater collection scheme. Inappropriate design and maintenance approaches to wastewater infrastructure facilities and funding are Principal reasons for insufficient sewerage systems/sanitation services in India. As Indian cities grew, their drainage systems did not keep pace with construction growth or water supply. The clutch on floodplains and insufficient sewerage systems that flow into storm drains prevent these drains from coping with the monsoon runoff (Gupta, 2007). The ability to intercept, evapotranspiration, store and infiltrate rainwater, reduced due to impermeable surfaces, compacted soils and removal of vegetation (Whitford et al., 2001).

Due to the complexity of such systems, numerical hydraulic models such as MIKE-Urban (DHI, Denmark) or Info Works CS (Wallingford Software, UK) have recently played a key role in understanding the performance of existing and proposed drainage networks. This ever-increasing demand can be met by creating effective water distribution and sewerage networks using advanced computational technologies, such as modern hydraulic simulation and design tools. Many researchers have reviewed the applicability of various rainfall-runoff models for urban areas and wastewater quantification (Nguyen and Venohr, 2021; Maryam et al., 2021; Primin et al., 2020; Anni et al.,2020; Livingston et al., 2020; Liu et al., 2020; Abdulla and Ullas, 2020; Hernes et al., 2020; Nguyen et al., 2020; Wang et al., 2019; Luan et al., 2018; Zolch et al., 2017). The hybrid sewage system and surface systems were also combined with the Storm Water Management Model (SWMM), which simulates the movement of the storm sewer system and the surface system (Kourtis et al., 2017; Katti et al., 2015; Shawl et al., 2015; Obaid et al., 2014).

The urbanization trend in Kerala had been comparable to that in India until 2001. Indeed, the level of development in Kerala (25.96%) was marginally lower in 2001 compared to India (27.78 per cent). The urbanization in Kerala rose from 2001 to 2011. Between 2001 and 2011, urban population decadal growth was 92.7%, and the rural population decreased by 25.6%. Between 2001 and 2011, Kerala's average exponential growth rate (AEGR) was 6.56%, compared to India's 2.76% (Table 1). In comparison to the rest of the world, Kerala's experience of urbanization has been unique. As a result, urbanization grew from 25.96% in 2001 to 47.72% in 2011. In Fig. 1, this sharp rise in urbanization is seen. There are two projections of the Kerala State Urbanization Report (SURK), which estimated the urban population for the State. The first scenario involves the continuation of the current tendency to increase urban density. The second case presumes that in the next two decades the annual development rate for the urban population is the same. In both cases, urbanization will increase by more than 90% by 2031 (State Urbanization Report, 2012).Keeping above in view, an attempt was made to design for the collection system network of Malappuram City using DHI's MIKE+ model.

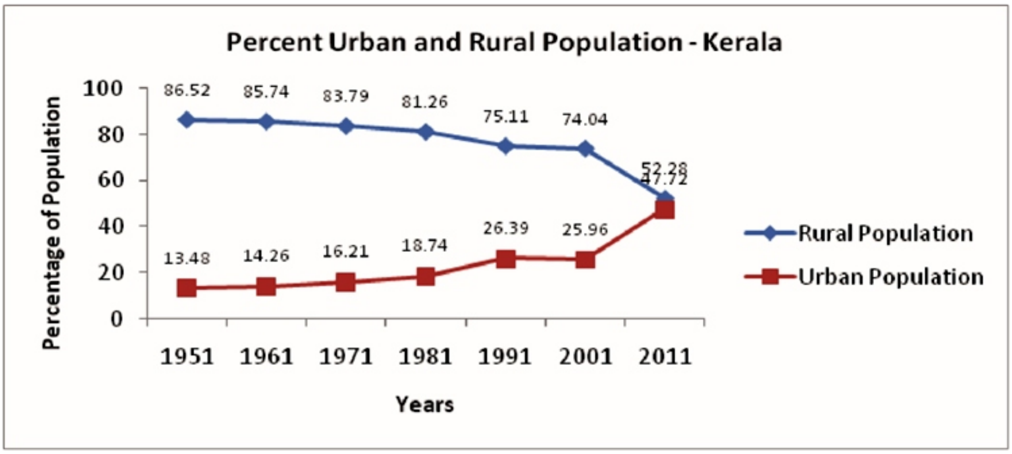

Fig. 1 Composition of the rural and urban population in Kerala: 1951–2011(%) (Census of India, 2011)

Table 1 Exponential growth rate of Kerala and India (%) during 1951–61 to (2001-2011 (Census of India, 2011)

Year	Annual exponential growth rate	
	Kerala	India
1951–61	3.25	2.34
1961–71	3.16	3.23
1971–81	3.15	3.68
1981–91	4.80	3.22
1991–2001	0.74	2.73
2001–2011	6.56	2.76

MATERIALS AND METHODS

Study Area

Malappuram district is bordered on the northwest by Kozhikode district, on the northeast by Wayanad district, on the east by the Nilgiri hills, on the southeast by Palakkad district, on the southwest by Thrissur district, and on the west by the Arabian Sea. Malappuram city is located in the state's midland (11.041°N 76.083°E). The Kadalundi River is one of the four main rivers in the Indian state of Kerala that pass through Malappuram. Malappuram narrowly passes the population mark to be a city with a town population of 101,386 people (census of India 2011a). The region has a population density of 1,742 per km^2, divided into 40 electoral wards. The city centre has a density of about 70 percent with a total of 68127 residents (Census of India, 2011a).The city of Malappuram, like most cities in Kerala, has developed organically and unplanned (Natarajan, 2008). The building density of the city is significantly different due to its topographic variations, the built-up portion is clustered in gentle slopes along NH 213 and SH 71, and the steeper areas in the western part remain small. The city thus takes on finger-city shape, where the formation of the ribbon along the roads is similar to that of fingers arising from the palm of the city centre. The district's average rainfall is 2793.3 mm. In general, the climate is warm and moist. The maximum temperatures range from 28.9 and 36.2 °C and minimum between 17.0 and 23.4 °C. The study area map of Malappuram city is shown in Fig. 2.

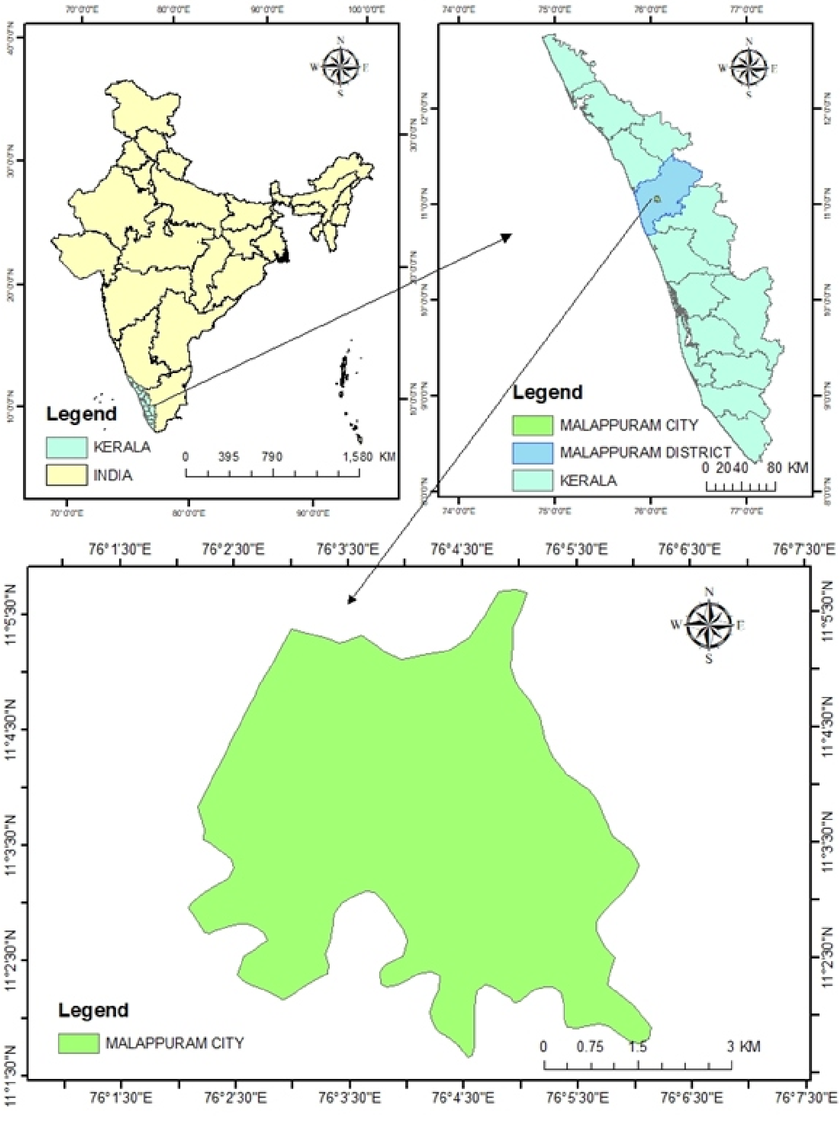

Fig. 2 Location map of the study area

Preparation of Input Data

The polygon map of Malappuram city was delineated by using Google earth pro kml format. Using MIKE+, it was further converted into a layer from kml format. As the elevation profile developed by total station survey or LIDAR survey was not available, a 30m digital elevation model of SRTM was downloaded from the official website of the Alaska satellite facility data search, NASA (https://search.asf.alaska.edu) and elevation value for each manhole of the study area was extracted by interpolation and assignment tool of MIKE+. Daily rainfall data of Malappuram city for the period (2017-2020) in dfs0 format was available with DHI. The building shapefile of the Malappuram city was obtained from the https://extract.bbbike.org/community.html website. With the help of this catchment imperviousness of the building, boundaries were given in the sub-catchment. The population forecasting for the design period of 30 years was carried out using the arithmetic increase method, incremental increase method and geometrical increase method by utilizing the population of the previous five decades, obtained from the Census of India website. For the year 2051, the projected population was 104252, 104869 and 146036 by using arithmetic increase method, incremental increase method and geometrical increase method, respectively. The distribution of the forecasted population over each sub-catchment was carried out by assuming 3 people in each house and has an area of 0.01672 hectares. The person equivalent and a number of houses were calculated by using the following formula.

$$\text{Person equivalent} = \text{no of houses} \times \text{no of persons in the house}$$

$$\text{No. of houses} = \frac{\text{catchment area (ha)} \times \frac{\text{imperviousness(\%)}}{100}}{\text{area of single house in hactare (assumed)}}$$

For Indian cities, a supply of 135 lpcd is considered in general (CPHEE, 1999). However, for this study area, catchment discharge was computed by taking a water requirement of 180 lpcd. The amount of wastewater produced was estimated to be roughly 80% of the amount of water provided. Therefore, total wastewater discharge was determined as illustrated below.

$$\text{Wastewater generated by each person} = 180 \text{ lpcd} \times 0.80 = 144\frac{l}{d} \approx 150\frac{l}{d}$$

$$\text{Total discharge of wastewater from catchment} = 150\frac{l}{d} \times \text{forecasted population}$$

$$= 150\frac{1}{d} \times 146036 = 21905400\frac{1}{d} = 21905.4\frac{m^3}{d}$$

Description of Mike+ Model

MIKE+ is an enhanced version of MIKE URBAN+ which was developed by the Danish Hydraulic Institute (DHI). The model includes an extra capability to combine a 1-D sewer network or a 1-D river with a 2-D overland to examine the effects of flooding in urban areas caused by a high rainfall event or a river embankment breach. MIKE+ works in three different modes such as i) Rivers, collection system and overland flows, ii) SWMM5 collection system, and iii) water distribution. MIKE+ enables us to simulate wastewater, storm water, rivers and overland flows and represents the hydrological, hydraulic, and operational processes in the 1D networks. The main module for collection systems is CS-Pipe flow and provides access to hydrodynamic network modelling and long-term statistics. The MIKE 1D hydrodynamic pipe flow model solves the whole St. Venant equations throughout the drainage network, allowing for the simulation of backwater effects, flow reversal, surcharging in manholes, free-surface, pressure flow, tidal outfalls and storage basins. It is capable of handling any form of a pipe network system with alternating free surface and pressurized flows, as well as open channel networks and pipes of any shape. The finite differences method is used to solve the non-linear set of equations. Dynamic pipe models during wet weather are automatically combined with basic hydrological models during dry weather periods. CS-Rivers are a key module for river networking that takes care of modelling of backwater effects, flow reversal, surcharging in closed sections, free-surface flows, tidal outlets, and reservoir storage.

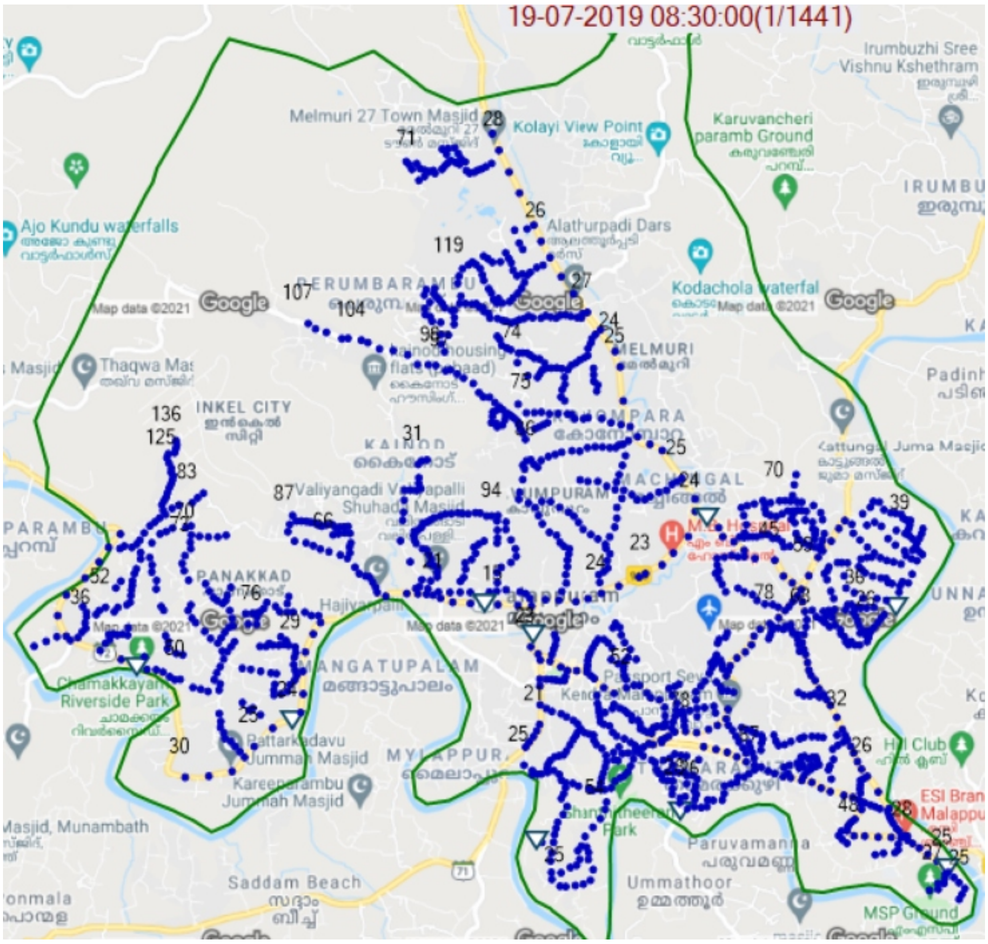

Fig. 3 Digitized manholes

Model Setup

A model is made up of nodes and structures, pipes and canals, weirs, orifices, curb inlets, pumps, and valves as hydraulic elements. The shapefile of the study area was initially projected in WGS_1984_UTM_ZONE_43N: A building shapefile was added as a feature layer to calculate the catchment imperviousness and inactive area for 2-D overland. A total of 1375 manholes were provided uniformly on the GIS map layer of MIKE+ at every change of direction and slope, depending on the size of the sewer by maintaining a minimum distance of 30m between two manholes (Fig. 3). The ground elevation was obtained from the digital elevation model of the study area using interpolation and assignment tools. The invert level of each manhole was determined by developing the sewer line profile. The manholes were having a diameter of 1.85 m, 1.5 m, 1.0m and 1.0 m on the trunk line, mainline, sub-main and lateral, respectively. Normally, cover type manholes do not allow water to overflow from the manhole instead. The spilling manhole cover type was chosen, which indicates that if the water level approaches and exceeds the node's ground level, water escapes from the model. It will spill all the excess water on the ground.

Pipes and Canals

The elevation profile was carefully analyzed to determine the position of the outlet at a lower elevation. Pipes and canal in MIKE+ are defined as a conduit connecting two nodes. A total of 1375 links were established in accordance with the road network, carrying wastewater to 9 outlets. It may be either a straight line or a polyline connecting two nodes and is expected to connect nearby nodes at bottom levels. All nodes were linked from higher to lower elevations in order to collect all water at various exits and immediately release it into local water sources, depending on the quality of the collected water. In MIKE+, the length of a connection is determined based on the shape of the line. Diameter of lateral, sub-main, main, and trunk sewers were taken as 0.15m, 0.3m, 0.6m, and 1m, respectively. Excavation of up to 5 m was permitted during the process of collecting all of the water at one location in order to preserve a slope in the sewage line. However, it exceeded in certain locations, but because the length of the excavation is short, it was considered successful. The created links of the collection system network are shown in Fig. 4.

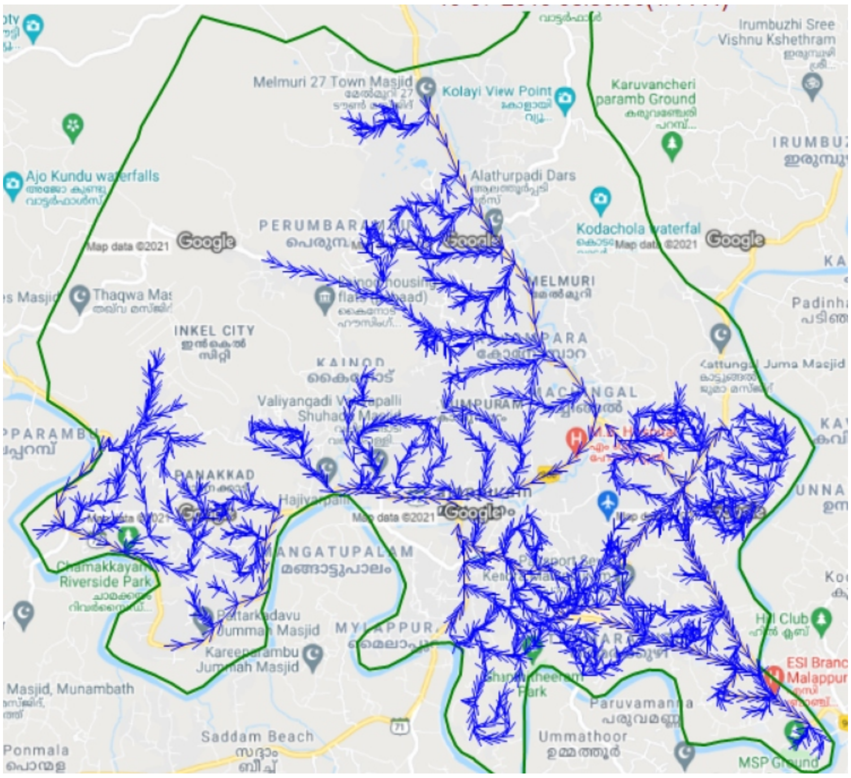

Fig. 4 Created links of the collection system network

Rainfall-Runoff Modelling

MIKE+ provides a capability to model the surface stormwater runoff modelling and urban catchment infiltration. MIKE+ includes "time area method", "kinematic wave", "linear reservoir" and "unit hydrograph method" as surface runoff models. The time area method was used for this study because it is a basic surface runoff model with few data requirements such as catchment imperviousness and time of concentration. The runoff computation in the time area method is based on a basic consideration of hydrological losses and runoff routing using the Time-Area curve.

The entire catchment of 33.62 km^2 was divided into 1384 sub-catchments, with each sub-catchment contributing to the runoff. MIKE+ catchments are modelled as hydrological units, with storm runoff and infiltration created using a single set of model parameters and input data. The imperviousness of the catchment was calculated by manually dividing the entire city of Malappuram into Zone- A, B, C, and D with varying imperviousness values of 30, 85, 70, 55 %, respectively using a satellite map in the background as shown in Fig. 5.As the high rainfall occurs throughout June, the simulation period included the whole month of June 2019. An adaptable time step with a minimum of 10s and a maximum of 60s time was chosen.

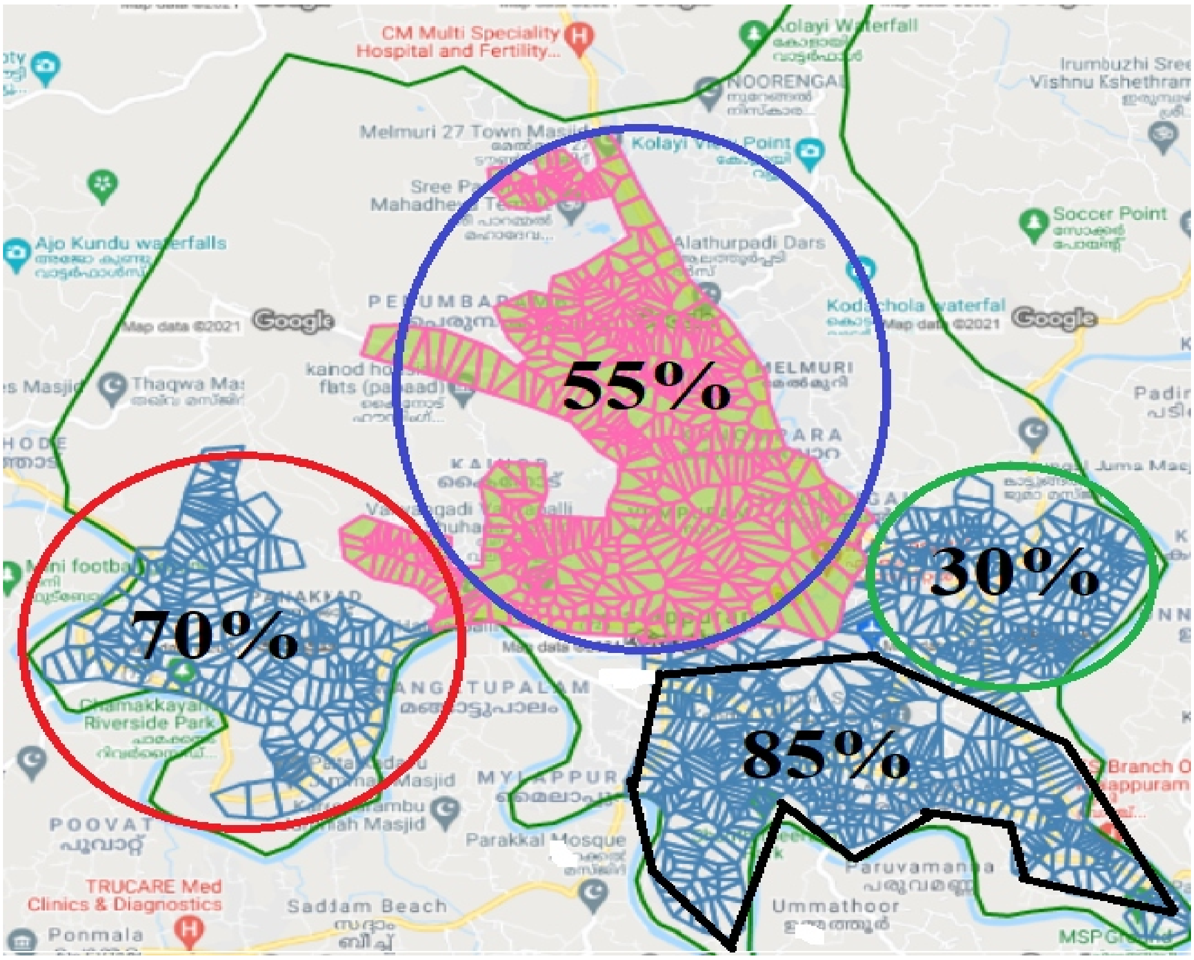

Fig. 5 Delineated catchment with imperviousness (%)

RESULTS AND DISCUSSION

The predetermined critical level of manholes was used to provide a clear image of the flooded nodes produced by the 19th June, 2019 rainfall event. A positive critical water level showed more water in the manholes than at the critical level. Similarly, the water level in the manhole is below the critical threshold if the time series value is negative. Manholes having water level 0.1m more than the critical level are shown in Fig. 6 and other details are provided in Table2.When the same model was run from August 1 to August 7, nearly 17 manholes were having water levels that are 0.1 m over the critical level. Similar run was made for August 19 rainfall event also.

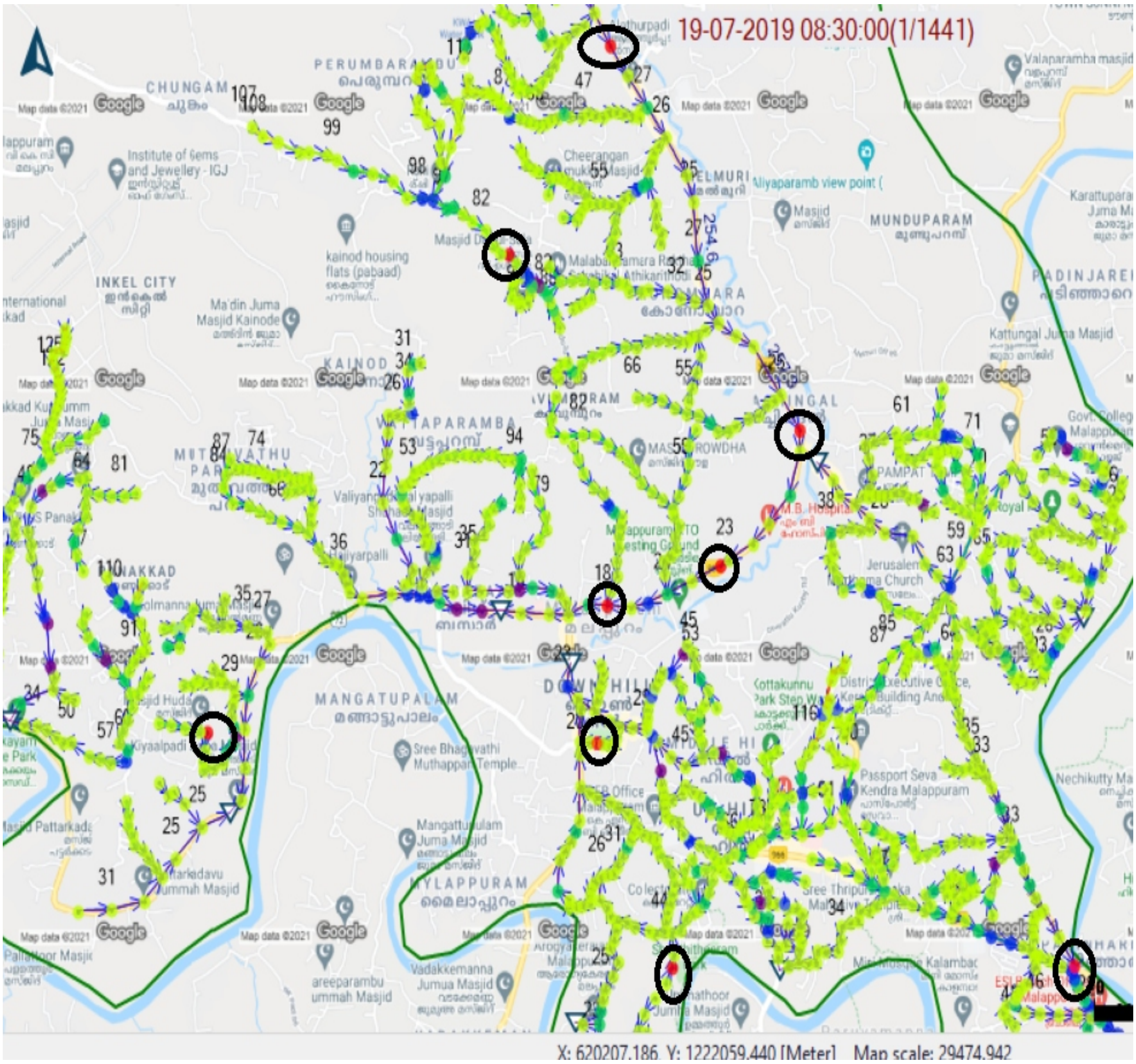

Fig. 6 Manholes having water level 0.1m above the defined critical level for 19 July

Table 2 List of manholes having water level 0.1m above the defined critical level for 19 July

ID	Node type	DIAMETER	GROUND LEVEL	INVERT LEVEL	CRITICAL LEVEL	MANHOLE DEPTH
Node_1712	Manhole	1	18	16.85	17.77	1.15
Node_1845	Manhole	1	47	46	46.8	1
Node_2468	Manhole	1.5	58	56.55	57.71	1.45
Node_25	Manhole	1.8	18	16.15	17.63	1.85
Node_2552	Manhole	1.5	76	74.55	75.71	1.45
Node_280	Manhole	1.8	23	21.15	22.63	1.85
Node_543	Manhole	1.8	22	20.15	21.63	1.85
Node_556	Manhole	1.8	21	19	20.6	2
Node_819	Manhole	1.5	79	77.55	78.71	1.45
Node_94	Manhole	1.8	24	22.15	23.63	1.85

Various sewer profiles with water levels were developed for the two simulation periods i.e., June 19th and 1-7th August. The total number of links in the network was 1375. The ground level has been demarcated by the green line; the bottom level is shown by the brown line. The critical level of manholes is shown by the red points and the maximum water level is shown by the dotted red line in all of these sewer profiles. Simulation period is as per the Meteorological history of the Malappuram city which shows high rainfall on 19 July 2019 and landslides due to heavy rainfall from 1-7 august 2019.Profile plots were developed for different trunks showing maximum water level for two different simulation periods (a) six-day simulation period, commencing at 08:30 on August 1 and finishing at 08:30 on August 7 (b) one day simulation period, commencing at 08.30 on July 19 and finishing at 08.30. On August 6 profile plot of trunk C, D at 18.06, Trunk K at 4.30, On August 7 trunk A,B,G at 08.30 and On July 19 profile plot of trunk K at 15.42, Trunk G at 10.30, Trunk D at 13.30, Trunk A at 17.30 and Trunk C at 23.30 hours. Profile plot of trunk-Gon July 19 at 10.30and trunk-A on July 19 at 17.30 demonstrating the maximum water level are shown in Fig. 7 and Fig. 8. Diameters of lateral, sub-main, Main, and trunk sewers are taken as 0.15m, 0.3m, 0.6m, and 1m, respectively.

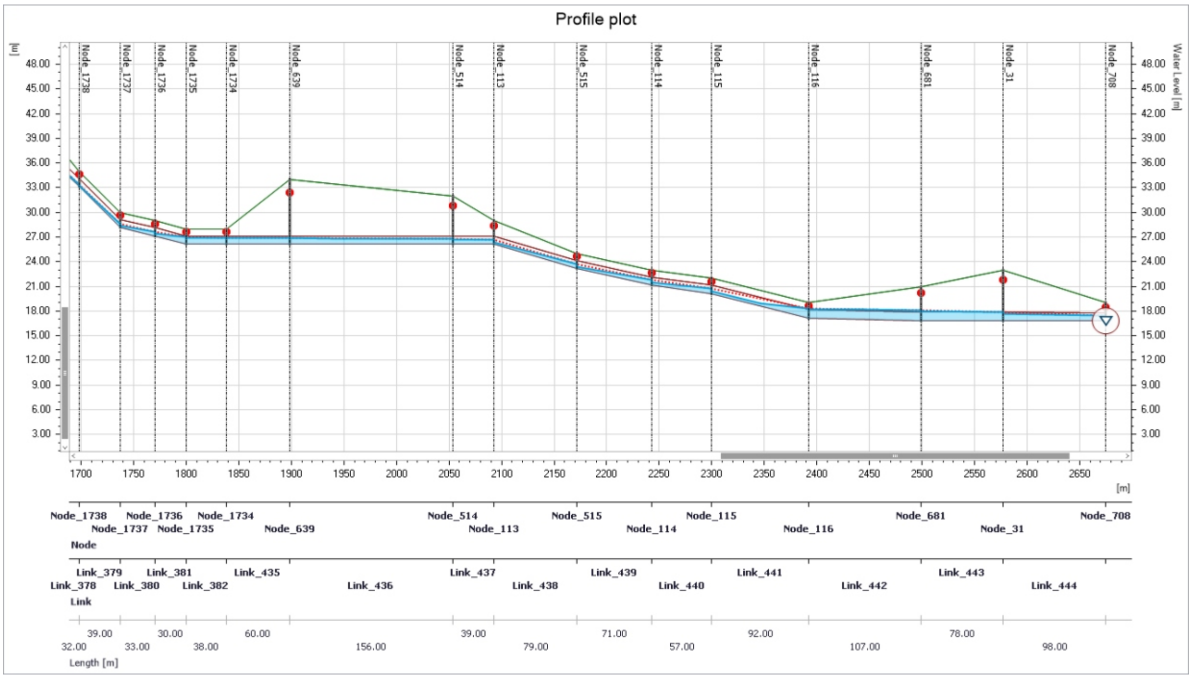

Fig. 7 Profile plot of trunk-G indicating the maximum water level for simulation period on 19 July at 10.30

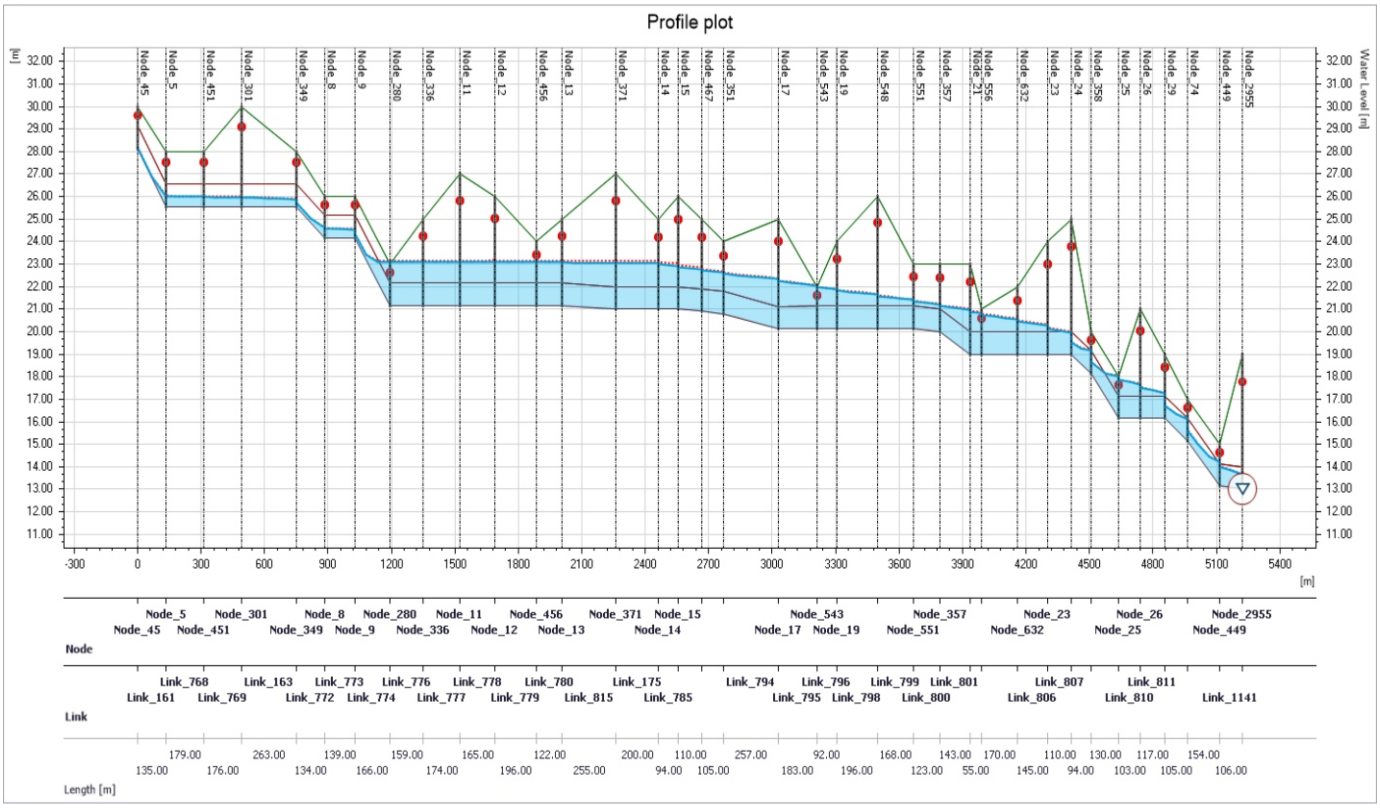

Fig. 8 Profile plot of trunk-A showing maximum water level for simulation period on 19 Julyat 17.30

CONCLUSIONS

In this study, MIKE+ model has been used to design a collection system network for Malappuram city situated over the hill in Kerala. A shapefile of the study area, SRTM 30m DEM, and rainfall data for the years 2017-2020 were used. The time area method was used to model the rainfall-runoff processes and catchment discharge was estimated by the rational formula for 1-D pipe network analysis. The goal of this study was to create a collection system network for the entire city of Malappuram. There was a total of 9 outlets in the whole study area, however, the majority of sewers were found to deliver the water to outlets at nodes near Malappuram city east gate, Chamakkayam Riverside Park, and at Akshaya center. Therefore, sewage treatment facilities may be developed at these locations to reduce the burden of waste in the Kadalundi River, Kerala. The diameters of the manholes were determined as 1.85m, 1.5m and 1mon the trunk line, main line, and sub-main and lateral, respectively. The diameters of the trunk sewer, main sewer, sub-main sewer, and laterals were set at 1m, 0.6m, 0.3m, and 0.15m, respectively. With these dimensions, the collection system network appears to be overdesigned, as flooding occurs only at a few sites. More data and information are necessary to provide optimal design. If the water level exceeds the set critical level, a point of concern is required. As a result, it is clear that the trunks Sewer A, G, and K require attention since the water level in these trunks exceeds the critical level. MIKE+ model was found to be convenient for such designing and such models are required to be used for appropriate design and scenario analysis.

REFERENCES

Annette, S., Claes, H., Gilbert, S. and Gustafsson, L. G. 2008. The Impacts of Climate Change and Urbanisation on Drainage in Helsingborg, Sweden: Suburban Stormwater. Journal of Hydrology, 350: 114-125.

Anni, A., Cohen, S. and Praskievicz, S. 2020. Sensitivity of urban flood simulations to stormwater infrastructure and soil infiltration, Journal of Hydrology, 588: 125028.

Abdulla, S. and Ullas, A. 2020. Design of Vaccum Sewerage System. International Research Journal of Engineering and Technology, 7(7): 2319-2323.

CPHEE. 1999. Manual on Water Supply and Treatment, Ministry of Urban Development, government of India, New Delhi.

Gupta, K. 2007. Urban flood resilience planning and management and lessons for the future: A case study of Mumbai, India. Urban Water Journal, 4(3):183-194.

Hernes, R., Gragne, A., Abdalla, E., Braskerud, B., Alfredsen, K. and Muthanna, T. 2020. Assessing the effects of four SUDS scenarios on combined sewer overflows in Oslo, Norway: Evaluating the low-impact development module of the Mike Urban model, Hydrology Research, 51(6):1437-1454.

Kourtis, I. M., Bellos, V. and Tsihrintzis, V. A. 2017. Comparison of 1D-1D and 1D-2D urban flood models, 15th International Conference on Environmental Science and Technology, 1–6.

Katti, M. and B.M., K. 2015. Design of Sanitary Sewer Network using Sewer GEMS V8i Software, International Journal of Science Technology & Engineering, 2(01):254–258.

Liu, Y., Zhang, S., Su, H., Wang, D. and Gu, Q. 2020. Modelling and Application of Urban Drainage Based on Mike Urban Model. IOP Conf. Ser. Earth Environ. Sci.474.

Livingston, A., Patel, H., Rumao, G., Vaghadia, G. and Godboley, B.J. 2020. Design of Sewer Network for Kophrad Village, Virar-Vasai, International Journal of Innovations in Engineering and Science, 5(6):15.

Luan, Q., Zhang, K., Liu, J., Wang, D. and Ma, J. 2018. The application of Mike Urban model in drainage and waterlogging in Lincheng county, China, Proceedings of the International Association of Hydrological Sciences, 379 :381-386.

Maryan, M., Kumar, R. and Thahaby, N. 2021. Assessment of the Hydraulic Performance of the Urban Drainage System due to Climate Change using DHI MIKE URBAN, Biomedical Research and Environmental Science, 2(4): 261-267.

Natarajan, B .2008. Cities of Kerala, Actually Small Towns. Marg. Mumbai.

Nguyen, H.H. and Venohr, M. 2021. Harmonized assessment of nutrient pollution from urban systems including losses from sewer exfiltration: a case study in Germany,Environmental Scienceand Pollution Research, 0944-1344.

Nguyen, T., Ngo, H., Guo, W. and Wang, X. 2020. A new model framework for sponge city implementation: Emerging challenges and future developments. Journal of Environmental Management, 253:109689.

Obaid, H.A., Shamsuddin, S., Basim, K.N. and Shreeshivadasan, C. 2014. ModelingSewer Overflow of a City with a Large Floating Population. Hydrology Current Research, 5(02):171.

Primin, O., Ten, A. and Khudyakova, D. 2020. Hydraulic calculations of storm sewer networks, E3S Web of Conferences, 163:03012.

Semadeni-Davies, A., Hernebring, C., Svensson, G. and Gustafsson, L. G. 2008. The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Suburban stormwater. J. Hydrol.350: 114-125.

Shawl, Z., Raina, Y. and Mir, S. 2015. Design of Sewerage System in Hilly Areas and Various Challenges: A Case Study on Design of Sewerage System in Baba Ghulam Shah Badshah University Rajouri, Jammu and Kashmir, India, International Journal of Innovative Research in Science & Engineering(IJIRSE), 3(3): 116-125.

State Urbanisation Report. 2012. A Study on the Scattered Human Settlement Pattern of Kerala and its Development Issues, Department of Town and Country Planning, Government of Kerala.

Wang, Y., Luan, Q., Wang, H., Liu, J. & Ma, J. 2019. Risk Assessment of Rainstorm Waterlogging in New District Based on MIKE Urban, Springer International Publishing.

Whitford, V., Ennos, A.R. and Handley, J.F. 2001. City form and natural process-indicators for the ecological performance of urban areas and their application to Merseyside, UK. Landsc. Urban Plan. 57 (2): 91–103

Zolch, T., Henze, L., Keilholz, P. and Pauleit, S. 2017. Regulating urban surface runoff through nature-based solutions-An assessment at the micro-scale. Environmental Research,157: 135-144.

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