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Nature and Science

MARSLAND PRESS
Multidisciplinary Academic Journal Publisher

Mathematical Model of the Influence of Urban Landscape Changes on the Dynamics of City Flooding due to Showers

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Abstract: As a result of global climate change, the number of weather anomalies in the form of heavy rains is increasing, which increases the risk of emergency situations. Cities were flooded in the arid climate of Central Asia far from river floodplains and even in desert regions. Due to the change in the infrastructure of urban areas and the increase in the area of surfaces covered with asphalt and concrete, impermeable materials, the rate of water filtration into the soil decreases and the rate of slope water flow increases. Anthropogenic change in the urban landscape leads to the flooding of basins and their rapid flooding occurs, which increases the risk of emergency situations. The article proposes a method for calculating the flooding of urban areas from showers based on a mathematical model of slope runoff. The proposed mathematical model and method for calculating the planned slope runoff in cities differs from the quasi-planned model, which will make it possible to identify territorial zones, the rate of their flooding and develop design recommendations to prevent dangerous manifestations of heavy rainfall. The hydrological model makes it possible to calculate the flow of water flows in plan for various landscapes with different surface coverage - grassy, shrubs, trees, asphalt, concrete, and others. When carrying out construction activities to change the urban landscape, it is necessary to take into account the possibility of flooding zones during heavy rains, especially with an increase in the number and intensity of extreme weather events associated with climate change.
[Myagkov S.V, Myagkov S.S., Khabibullaev Sh. **Mathematical Model of the Influence of Urban Landscape Changes on the Dynamics of City Flooding due to Showers.** *Nat Sci* 2021;19(4):5-9]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 02. doi:10.7537/marsnsj210423.02.

Key words: mathematical model, urban flooding**,** landscape, flooding, shower, climate change

1. Introduction

In the period 2019-2022 years the heavy rainfall occurred in the countries of Central Asia and there were floods in cities located in the deserts - Samarkand, Bukhara, Tashkent, Ashgabat. Heavy rainfall is attributed to climate change. Climate change has led to an increase in the number of heavy rainfalls on a global scale by 140% (Arambepola N., 2017), especially in deserts.

Desert showers have also previously been observed but have increased in frequency (Center for Neighborhood Technology, 2011) . The volume of precipitation per rain increased and especially the intensity (volume per unit of time). At the same time, floods in cities leading to damages began to be observed more often (Dobrowolski S., 2006).

Inundation of urban areas is associated with climate change which increases the amount of heavy rainfall in large areas of watersheds. The rivers overflow with water and the rising water level in the rivers leads to the flooding of the surrounding areas.

Urban flooding due to drainage systems being overwhelmed by rainfall is estimated to cost £270 million a year in England and Wales; 80,000 homes are at risk. Its impacts are expected to increase if no policy changes are made. This sets out the current approaches to managing urban drainage and examines proposals for improving them. (Dammalage T., 2019).

The main difference between most urban areas of European cities and Asian cities is the location in the lowlands of the drainage basins. European cities are located in floodplains and desert cities are located on the territory of flat plains. This difference leads to the fact that the cities on the plains have depressions, which are filled with water during a downpour. Cities located in floodplains take on the impact of the elements expressed by the inflow of water from the drainage basin (Idris S., 2015).

As a result of the inevitable development of cities, the landscape is changing. Roads, buildings, bridge structures, tunnels and so on are being built. There is not only a change in the terrain but also there are depressions and elevations that change the direction of currents (Jingxuan Z., 2018). The flooding of urban areas leads to an increase in economic losses and often in human casualties (National Flood Insurance Program Community Rating System , 2013) .

As a result of anthropogenic changes in urban landscapes with a change in the hydraulic properties of the surface, there was a decrease in filtration into the soil and an increase in the speed of water movement along the catchment surface. The cost of damage from urban flooding is increasing which is associated not only with flooding, but also with the development of urban infrastructure and the increase in the area occupied by structures (The Prevalence and Cost of Urban Flooding, 2015) .

Changes in the infrastructure of cities - increased coverage of watershed areas with roads, bridges, new buildings and other structures has led to a change in the terrain. More roads, concrete sidewalks led to an increase in the speed of water flows. Decreased areas of grassy lawns, reduced areas of soil cover reduce the total number of surfaces with the possibility of water seepage into the ground.

2. Object of research

Consider the flooding of the urban area on the example of the city of Tashkent. In the center of the city is the ancient Chorsu square, comparable in age to the city of Tashkent. The place is historical and the time of foundation of the square is not less than 1000 years. Intensive construction on the territory of the square began to develop in the last 100 years. The square got its name from the four springs that existed in its place, the sources of the Aktepe River. Chorsu ("Chor" - four, "Suv" - water) - four waters or four springs. As a result of many years of construction on the territory of the square, springs were filled with soil and buildings were built on the covered lands.

The photo shows photographs of the area in 1890 and 2020 (Fig. 1, Fig. 2).

Figure 1. Tashkent city, Chorsu square. Photo 1890 year.

The change in relief is clearly visible - a ravine (1890) and a covered ravine (2020). In ancient times, when there were showers, water flowed into the ravine, now there is no ravine and water accumulate in the area causing flooding. In addition, if earlier the water flowed slowly, now the flow rate has increased as a result of the change of soil cover to asphalt and concrete, through which the flow of water has a greater speed.

The risk of floods increases with a decrease in the filtration capacity of the underlying surface and the closure of runoff from the surface (Rosenzweig B., McPhillips L., 2018).

Often the model of flood is carried out as quasi-2D. The relief is represented as connected watersheds and the flow of water is represented as connected streams. In this case there are no flood zones and there are no zones of water accumulation depressions (Muhammad H., 2022).

3. Plan flow calculation model

A quasi-planned filtration model is built as a set of channel flows. The watershed is represented by a connected set of stream networks in each of which a single stream with inherent characteristics is formed and the movement of water in a single stream is described accordingly (Myagkov S., 2022).

All network flows merge at exit points to the main channel (Rosenzweig BR, 2021). The basis of such models is the Bernoulli equation.

A common form of Bernoulli's equation, valid at any arbitrary point along a streamline is:

$$v^2/2 + g\,z + p/\rho = constant \qquad (1)$$

where: v is the fluid flow speed at a point on a streamline, g is the acceleration due to gravity, z is the elevation of the point above a reference plane.

Figure 2. Tashkent city, Chorsu square. Photo 2020 year.

With the positive z - direction pointing upward – so in the direction opposite to the gravitational acceleration, p is the pressure at the chosen point, and

ρ is the density of the fluid at all points in the fluid (Sagdeev N., 2022).

This equation (1) is applicable for conditions when the water flow lines do not change their direction and the main condition is that there are no pits for water accumulation. Thus, flooding leads to an increase in the water level in some areas and the flow of water from one pit to another in this design scheme is impossible.

The following approach is proposed. Some drainage surface is represented as a grid from a set of elementary areas for each of which the water balance equation is fulfilled:

$$\frac{dW_j}{dt} = X_j + \sum_{i=1}^{4} Q_{ji} - P_j \qquad (2)$$

where W_j is the amount of water on the surface of element j, X_j is the precipitation per element, $\sum_{i=1}^{4} Q_{ji}$ is the inflow of water into the element or the outflow of water from the element, P_j is the filtration of water into the soil.

The exchange of water between elements is calculated using the Chezy formula:

$$Q_{ji} = AC\sqrt{rS} \qquad (3)$$

where A is the cross-sectional area of the flow, C is the Chezy discharge coefficient, r is the hydraulic radius and S is the slope of the water surface.

The cross-sectional area of the flow is determined as the average value of the height of the water layer in the elements: $A_{ji} = B*(h_j + h_i)/2$, B is the width of the grid cell, h is the height of the water layer in the element.

The direction of the flow is determined by the difference in the height of the water layer with the height of the element.

Slope of the water surface: $S=(h_i+Z_i-h_j-Z_j)/B$, Z - elevation of the earth's surface.

The amount of precipitation per element is given by a matrix of X values over the entire surface. Water filtration is set for each element of the digital elevation model. For metal coating (building roofs), asphalt (roads), concrete (sidewalks) P=0.

For grassy lawns and surfaces with vegetation P is taken as a certain function of time for which in the initial period, the amount of water is spent on wetting the surface of the leaves and then penetrates into the soil to a certain depth, and only then does the water begin to flow along the slope.

In the form of an equation, this position can be represented as an equation:

$$P=\alpha*EXP(\beta), \qquad (4)$$

where α, β – parameters of deciduous or herbaceous cover.

4. Model calculations

Using the presented model, calculations were carried out for showers of various intensities. The explicit Euler scheme was used for the numerical implementation of the model. This design scheme is considered in detail in (Myagkov S., 1995).

Some territory is presented in the form of a matrix of earth height values according to a digital elevation model. A digital elevation model was used based on satellite information which, as you know, has objectivity but for the refinement of the relief, the surface is integrated, especially in urban conditions. Relief data integration occurs when a part of a building with a height of more than 10 meters and a part of the relief fall into one display element, and elevations are averaged (Alahacoon N., 2018) .

$$h_j^{t+1} = h_j^t + \frac{\tau}{B}\left[X_j - P_j + \sum_1^4 (h_i + Z_i - Z_j)\right]^t \qquad (5)$$

Where h_j^t is the height of the water layer of element j at time t, X_j is the intensity of the shower, P_j is the intensity of absorption, Z_j is the relief mark. The input data for calculating the parameter matrix are rainfall intensity, relief, soil infiltration parameters, landscape coverage characteristics, and others. Soil or concrete cover values for landscape representation are represented by soil seepage coefficients from 0 to 1, depending on the vegetation. As the initial values the water layer from the intensity of precipitation was used.

Figure 3 shows a graph of the filling of the deepest mark of the territory during showers of various intensity of 8 and 10 mm per minute.

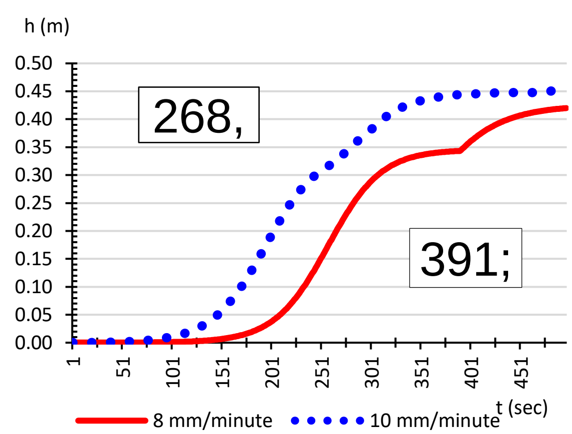

Figure 3. Graph of the filling of the depression during a shower of varying intensity.

A break in the line shows that some depressions of various depths are being filled in the area from which water begins to overflow into a lower depression.

With more intense rain of 10 mm per minute, overflow occurs at 268 seconds, and with rain of 8 mm per minute at 391 seconds from the onset of rain. And then there is a further filling of the cavity with a maximum depth. Figure 4 shows the plan of flooding the urban area of Chorsu Square. The arrows show the direction of flow in plan. The contours of buildings and structures are represented by lines.

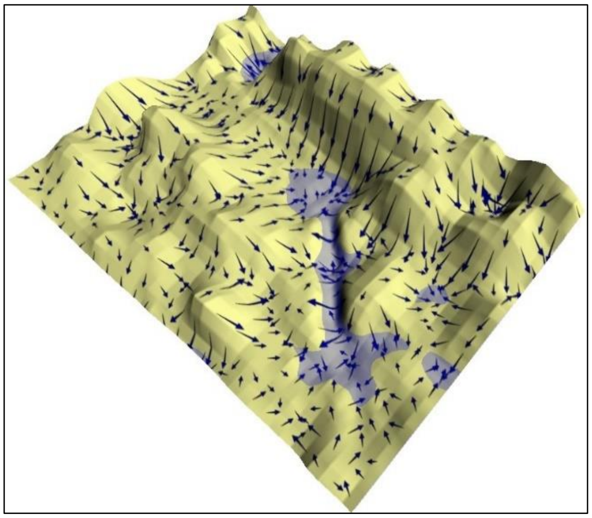

Figure 4. Contour filling contours on the urban landscape. The arrows show the directions of the flow over the surface as a result of the shower. Lines of the structure and construction of the city.

5. Result

As a result of the change in the structure of the soil surface, the properties of the flow have changed. Two main properties have changed.

First, on a new asphalt or concrete surface, there is no filtration of water into the soil and no accumulation of water in the leaves of vegetation.

Second, the speed of water flow over asphalt or concrete is 10 times faster than over clay soil or soil covered with leaves, which increase the resistance to flow.

Thus, the filling of the cavity occurs in waves and much faster, which increases the threat of a dangerous situation with a threat to people's lives.

Such rapid filling leads to the risk of emergencies. There is a video on the Internet showing the case of a woman falling into a stream (https://mover.uz/watch/MEYCCKNj). As a result of heavy rain, the underground passage was flooded and a threat to life was created.

6. Discussion

Calculations according to the planned flow equation make it possible to calculate the water flow in the plan and terrain with different landscape coverage.

The design of buildings and landscape changes must be carried out with preliminary calculations of the movement of water on the surface. Changes in streamlines on the scale of one structure can lead to the reshaping of currents and the emergence of flows that will lead to local flooding of territories with a subsequent risk of emergencies.

Observed urban floods are caused by heavy rains and low drainage capacity of urban areas to divert water outside the city.

Heavy rains and associated floods have major economic and social impacts. These losses will increase if there are no changes in the management of the city's drainage system.

The use of alternative drainage methods can help in some situations, especially in small floods, but there are barriers to their wider use.

Some experts believe that the public will have to accept more frequent short-term flooding of certain areas in order to prevent the consequences of more devastating floods in large areas.

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Reference

[1]. Alahacoon N., Matheswaran K., Pani P. (2018) Decadal Historical Satellite Data and Rainfall Trend Analysis (2001–2016) for Flood Hazard Mapping in Sri Lanka, Remote Sensing, Vol. 10, no. 3, pp. 448-465, 2018

[2]. Arambepola N., Iglesias G., (2017) Effective strategies for urban flood risk management, Expert Group Meeting on Innovative Strategies Towards Flood Resilient Cities in Asia-Pacific, Bangkok, Thailand

[3]. Center for Neighborhood Technology, (2011) Urban Flooding in the Great Lakes States: A Municipality/ Utility Survey Report (Chicago: CNT, 2011), 1.

[4]. Dammalage T., Jayasinghe N. (2019) Land-Use Change and Its Impact on Urban Flooding: A Case Study on Colombo District Flood on May 2016. Engineering, Technology & Applied Science Research Vol. 9, no. 2, 2019, 3887-3891

[5]. Dobrowolski SG, Istomina MN (2006) Floods of the world. Moscow: Geos, 2006, 256 p.(in Russian)

[6]. Idris S., Dharmasiri L., (2015) Urban Development and the Increasing Trend of Flood Risk in Gombe Metropolis, Nigeria, International Journal of Science and Research, Vol. 5, no. 8, pp. 500-504, 2015
[7]. Jingxuan Z., Qiang D., Yinghui D., Aorui Z., Yingzhe Z. (2018) Indirect Damage of Urban Flooding: Investigation of Flood-Induced Traffic Congestion Using Dynamic Modeling Water. 2018, 10, 622; doi:10.3390/w10050622
[8]. Myagkov S. (1995) A model of water and salt exchange between a river and groundwater. IAHS-AISH Publication, 1995, (229), pp. 249–254.
[9]. Myagkov S.V., Khabibullaev Sh., Myagkov S.S. (2022) Modeling the Runoff of Mountain Rivers in the Ferghana Valley based on the Multivariate Regression Equation. *Nat Sci* 2021;19(7):1-4 doi:10.7537/marsnsj200722.01.
[10]. Muhammad H, Mehdi A. (2022) Experimental investigation of long-throated the accuracy of flow discharge measurement in trapezoidal canals. *Nat Sci*.2022,20(9):28-34. doi:10.7537/marsnsj200922.04
[11]. National Flood Insurance Program Community Rating System. (2013) March 21, 2013, http://www.fema.gov/national-flood-insurance-program/national-flood-insurance-program-community-rating-system .
[12]. Rosenzweig, BR, Herreros Cantis, P., Kim, Y., Cohn, A., Grove, K., Brock, J., et al. (2021). The value of urban flood modeling. Earth's Future, 9, e2020EF001739. https://doi.org/10.1029/2020EF001739
[13]. Rosenzweig, BR, McPhillips, L., Chang, H., Cheng, C., Welty, C., Matsler, M., et al. (2018). Pluvial flood risk and opportunities for resilience. Wiley Interdisciplinary Reviews: Water, 5(6), e1302. https://doi.org/10.1002/wat2.1302
[14]. Sagdeev N, Adenbaev B. Preticipation as Flow Formation Factor in Amudarya. *Nat Sci* 2022,20(12):28-43. doi:10.7537/marsnsj201222.05
[15]. The Prevalence and Cost of Urban Flooding. (2015) A Case Study of Cook County, IL. 2013-2014

4/12/2023