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A Geo-spatial Model for Flood Hazard Mitigation

(With Reference to Ja-Ela Divisional Secretariat Division - Sri Lanka)

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Abstract— Natural disasters are becoming more frequent, growing more severe and affecting more people than ever before. Among them, flooding can be identified as a natural event which has always been an integral part of the geological history of the earth. Pre-disaster management has become more important in the field of contemporary disaster management plan; particularly disaster mitigation. Flood mitigation involves the management and control of flood water movement, such as redirecting flood run-off through the use of floodwalls and flood gates and using dry/wet proofing methods. The most effective way to reduce the flood risk is through the vulnerability maps and flood models. Advancements in Geographic Information Systems (GIS) and Remote Sensing help in real time monitoring, early warning and quick damage assessment for disasters. The Flood Mitigation Model is a Geo-Mathematical Model to pre-estimate flood heights and to create a flood vulnerability map for any area with respect to Slope, Rainfall Intensity, Storm duration and the data of past flood events. In this study, Ja-Ela Divisional Secretariat, which is situated in Gampaha District, Western Province, Sri Lanka has been selected and the flood data of year 2016 is used. Vulnerable Roads and Buildings have been identified by comparing two rainfall intensities with the same storm duration and the model can be applied to any area of any country.

Index Terms— Disasters, Flood Mitigation, GIS, Rainfall Intensity, Slope, Vulnerability, Watershed

1 INTRODUCTION

A natural disaster is a major adverse event resulting from natural processes of the Earth; examples include floods, hurricanes, Landslides, tornadoes, volcanic eruptions, earthquakes, tsunamis, and other geologic processes. A natural disaster can cause loss of life or property damage, and typically leaves some economic damage in its wake, the severity of which depends on the affected population's resilience or ability to recover and also on the infrastructure available.

As a result, developing the tools, processes and best practices to manage natural disasters more effectively is becoming an increasingly urgent global priority. Effective disaster management or disaster response can be defined as providing the technology, tools and practices that enable disaster response organizations to systematically manage information from multiple sources and collaborate effectively to assist survivors, mitigate damage and help communities rebuild.

In many countries, the people and organizations that work in disaster management also have responsibilities related to national security. The processes and technology solutions they use for critical infrastructure protection can also be adapted for disaster management. These responders increasingly rely on information and communications technology (ICT) systems that can streamline knowledge sharing, situational analysis and optimize collaboration among organizations. ICT can help reduce the loss of life and property, reunite families and alleviate human suffering by providing first responders with the tools for effective communication and collaboration to overcome challenges posed by distance, diverse languages, cultural differences, geographic barriers, international borders and damaged infrastructure.

There are several factors which cause for flood hazard, including, Geological causes, and Human causes. Typical landform and excessive rainfall are the main reasons for floods which can be considered as Geological causes. Moreover, Slop of Catchment, Magnitude of Catchment, Soil type, Catchment shape, Climatic changes can be taken account. When it goes for Human causes, unplanned land use, improper/poor drainage systems, unplanned road constructions and deforestation are the main man-made causes for flood.

The most effective way of reducing the risk to people and property is through the production of flood risk maps. Most countries have produced maps which show areas prone to flooding based on flood data. The most sustainable way of reducing risk is to prevent further development in flood prone areas and old waterways. It is important for at-risk communities to develop a comprehensive Floodplain Management plan.

Remote sensing and GIS techniques have successfully established its application in the areas of flood management, such as Flood inundation mapping, River Morphological studies, Flood plain zoning and flood modeling.

The proposed Research will identify and model the floodplains in Ja-Ela Divisional Secretariat Division, with the use of digital data and the risk assessment will be conducted to cognizance the most affected areas using flood records of the year 2016.

2 LITREATURE REVIEW

Sri Lanka is imperiled by many types of natural hazards. Hydro-meteorological related disasters such as floods, landslides, cyclones and land subsidence are the primary hazards. The level of exposure to hazardous events has increased by expanding population and unplanned urbanization. The most frequent natural hazards that affect Sri Lanka are droughts, floods, landslides, cyclones, vector borne epidemics (malaria and dengue), and coastal erosion(Tissera, 1997).

Flood is one of the calamitous natural hazards in the world. Flooding poses a threat to many millions of the citizens in the world. On the global scale, storms and floods are the most destructive of natural disasters and cause the greatest number of deaths (Tucker, G.E, et al, 2001). According to Houston

(2011), Flooding means, an area is under water. The European Union Floods Directive (2007) defines a flood as a covering by water of land not normally covered by water. Silva, F. V., et al, (2014) says, "Floods are periodical events that occur primarily by water overflowing from the main drainage channel of natural or artificial systems to the adjacent areas, occupying riparian areas and floodplains".

A Flood can be amplified by human activities that interfere in hydrological cycle, such as soil sealing, vegetation cover removal, flow channel modification, reservoir construction, along with susceptible flood area occupation (TUCCI, 2011).

Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to convey excess water. However, floods are not always caused by heavy rainfall. They can result from other phenomena, particularly in coastal areas where inundation can be caused by a storm surge associated with a tropical cyclone, a tsunami or a high tide coinciding with higher than normal river levels. Dam failure, triggered for example by an earthquake, will result in flooding of the downstream area, even in dry weather conditions (Geo Science Australia, (n. d.)).

As the Ministry of Disaster Management indicates, Flood is the most frequently occurring natural disaster, mostly due to monsoonal rain or effects of low pressure systems. Sri Lanka National Report on Disaster Risk, Poverty and Human Development Relationship (2009) indicates that, With respect to spatial distribution floods appear to occur mostly in the districts of Kalutara and also in areas like Colombo, Gampaha, Matara and Jaffna. With respect to DS divisions, the highest incidence of flooding appears to occur in the Western parts of the island while most other DS divisions have a low incidence of flooding.

The Colombo – Katunayake expressway has been constructed in the area of Muthurajawela wetland from Mabola to the 18th Mile post of Katunayake and a levee has been constructed, 20m height and 50 m width using sea sand by blocking the canal network. It made a huge impact on surrounding people, generating overflows in rainy seasons, October 2006 (Kaludewa, 2007).

The landfilling of Muthurajawela wetland has generated a huge impact on surrounding areas by floods. Kerawalapitiya Gas Center, Kerawalapitiya Power station, Ja- Ela luxury housing scheme can be identified as the constructions which have been done by landfilling the Muthurajawela wetland (Rev. Iddamalgoda, 2010).

According to Kaludewa (2007), another reason for Floods in Ja-Ela Divisional Secretariat Division is the sea sand Mining from the debris comes through pipes, 80% sediment and water and 20% sand. This debris flow is released to the Hamilton canal and the adjacent canal system. This has been caused to block the small canes and it generates floods.

Rainwater of Gampaha district flows into the Negambo lagoon through the Attanagalu Oya. The Weliwita hatch is the last hatch which is across the aththaagalu Oya. It is located at 500m away from Kotugoda Bridge in Ja- Ela – Minuwangoda main road. The hatch has a 20 feet one opening and flow is very low and it makes floods in Ja–Ela, Katana, Minuwangoda and Gampaha Divisional Secretariat Divisions.

There are several formulas to estimate Flood with different parameters. Historical data and ongoing data campaigns are vital components of any forecasts of flood flows, including, Manning's Equation, Unit hydrograph and SCS methods, The Rational Method, Rules of thumb for changes in regional flood frequency, Storage-routing models and Catchment hydrology models.

For the last two decades advancement in the field of remote sensing and geographic information system (GIS) has greatly facilitated the operation of Flood mapping and Flood risk assessment. It is evident that GIS has a great role to play in natural hazard management because natural hazards are multi - dimensional and the spatial component is inherent (Coppock, 1995).

3 METHODOLOGY

The Geo- Spatial Flood Mitigation Model will be introduced using Secondary data from the survey department, Disaster Management Centre and the Divisional Secretariat Office of Ja-Ela.

ArcGIS 10.3 package will be used as the software to illustrate the spatial analysis and to construct models.

3.1. Study Area

Ja-Ela Divisional Secretariat is a Divisional Secretariat of Gampaha District, situated to the North of Colombo, of Western Province, Sri Lanka, in between 79.871°E - 79.871°E and 7.029°- 7.120°N. It is bounded by Aththanagalu Oya to the North, Colombo- Katunayake Expressway to the West, Mahara Divisional Secretariat Division to the South and Gampaha Divisional Secretariat Division to the East. The Divisional Secretariat Division consists of 57 Grama Niladari Divisions, within the area of 61.42km^2. The Divisional Secretariat Division is situated in the wet zone with rainfall ranging from 1400-2500 mm per annum. Both monsoons provide almost equal amounts of precipitation, about 33% of the annual precipitation is accounted during the North- East monsoon and the balance is due to the inter-monsoonal rains and localized convectional precipitation.

3.2. Data and Data variables

1:10,000 data set from sheet 59 and affected peoples' data will be taken account in the Research from the department of survey, Disaster Management and Divisional Secretariat office. All the data belong to the category of secondary data and available as feature classes. Then the 1:5000 contour layer was created, using 'Crete contour Tool' in ArcGIS Software, to get a more accuracy.

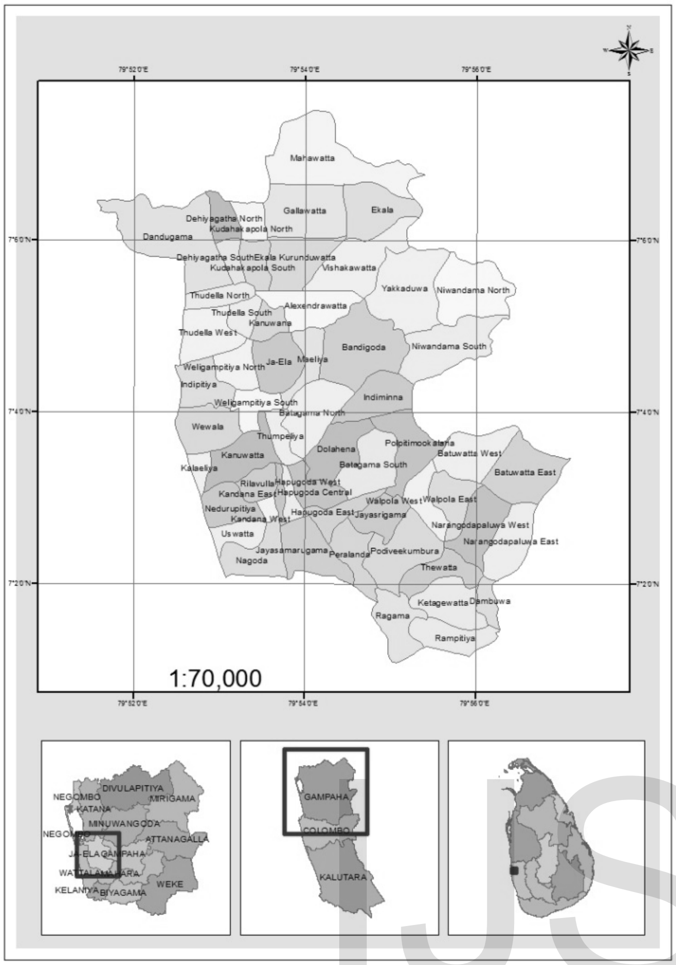

Figure 1: Study Area

In addition the values of the coefficient of Runoff (K/ K.R.) and the coefficient c will be used during the calculation of flood height. By considering the soil condition in the catchment area the coefficient of Runoff is in between 0.40 and 0.60, since the soil of the area falls in the category of slightly permeable, partly cultivated or covered with vegetation. In this case 0.50 is used by taking the average value (See the Appendix 1). The coefficient c will be 0.0365, in accordance to Richards (1955).

3.3. Methodology

A single model will be introduced to give outputs including, 3D Flood model with duration and flood height, watershed and Flood zonation map.

The total influence of the three Raster layers, Flood Height, Distance to the water feature and affected people has taken as 30%, 35% and 35% respectively. The influences of the three layers are same, but the influence of flood height is reduced, since the other two layers are especially in the residence and commercial areas. As an example, if there is an abundant paddy land it is a waste to calculate flood since there will not be any impact on the people, buildings or crops.

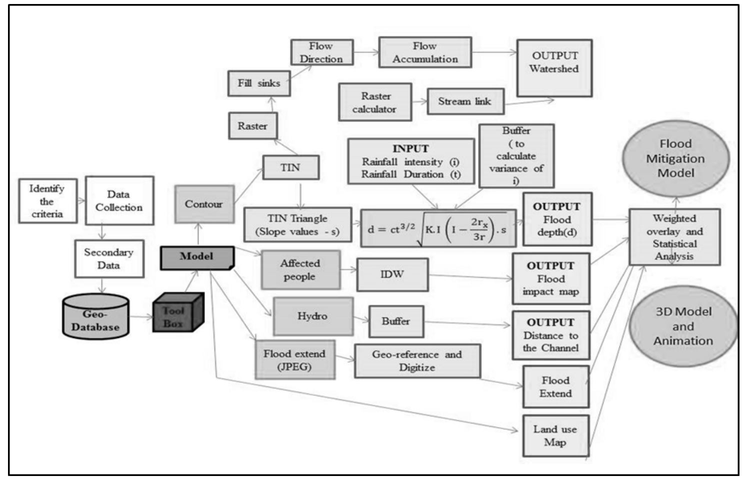

Figure 2 : Methodology

4 Data Analysis

As a comparison, in the selected storm point, 220mm rainfall intensity with 5 hour duration and 150mm rainfall intensity with same duration is taken.

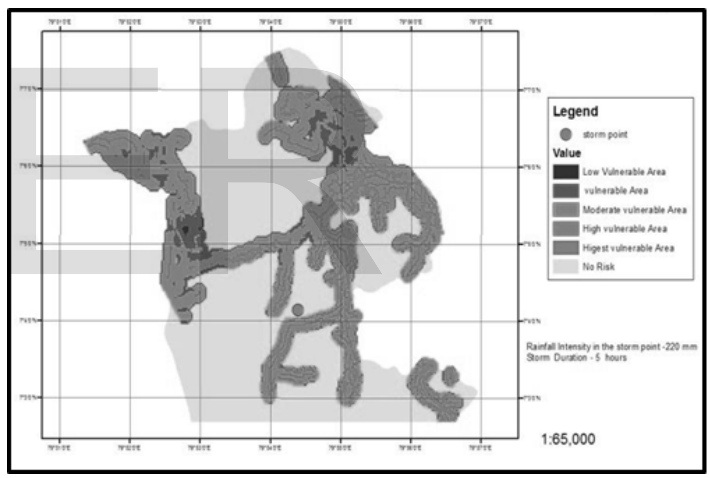

Figure 3 : 220 mm Flood

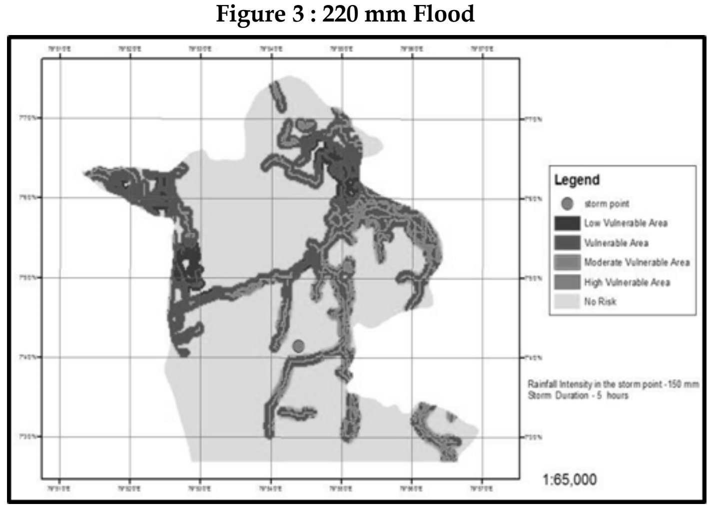

Figure 4 : 150 mm Flood

Approximately, 33% of Total Land area will be flooded in the first situation and 21% in the second situation.
To Analysis the Flood impact, the vulnerable areas are analyzed with the Land use, buildings, Roads and Watershed layers. The example flood, 220 mm rainfall intensity and 5 hours storm duration is used to analyze the model.

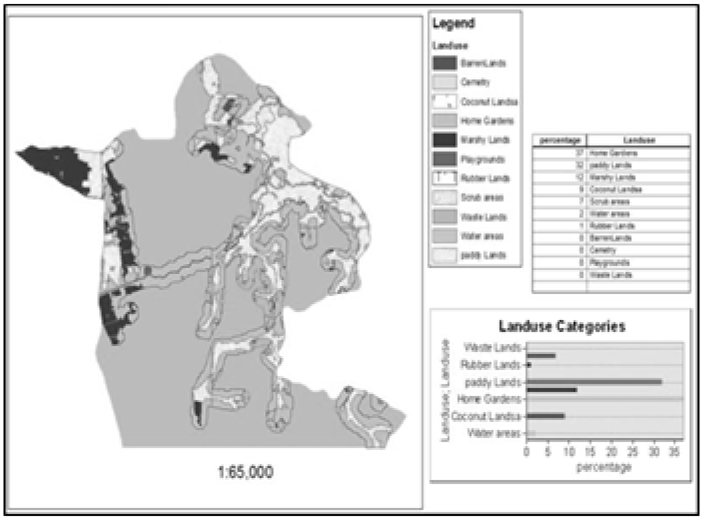

Figure 5 : Landuse Categories

The major effect will be in the category of Home Gardens (37 %) and Paddy lands. The impacts on paddy lands are not much important since the majority of the paddy lands are abounded and the 2% of water lands should be neglected.

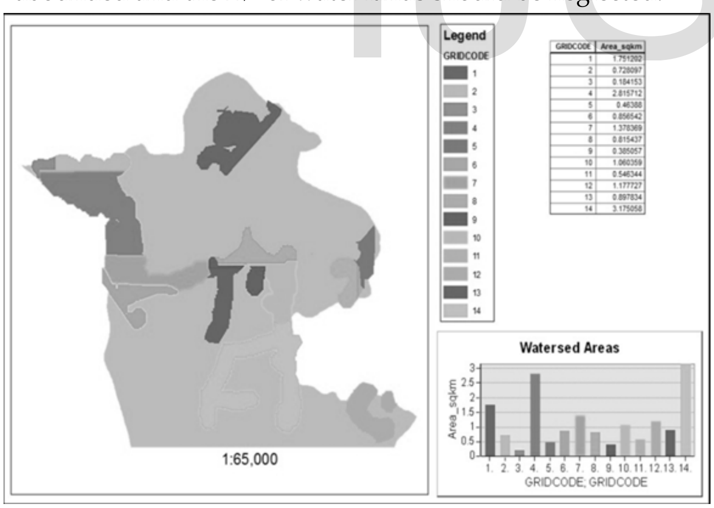

Figure 6: Watersheds

In accordance to the example flood, all the watersheds are vulnerable for the Flood and the fourteenth (Indiminna, Dolahena, Batagama and Bandigoda) and the fourth (Thudella, Dandugama, Dehiyagatha, Kanuwana and Weligampitiya) Watersheds are most vulnerable to the flood hazard, considering the total vulnerable area.

Total 847 Roads in Ja-Ela Divisional Secretariat Division are influenced by the 220mm flood during 5 hours, neglecting the expressways and the bridges, including four high vulnerable main roads a footpath and a railroad and 427 minor roads. Total 42 Main roads and 151 secondary roads are vulnerable to flood.

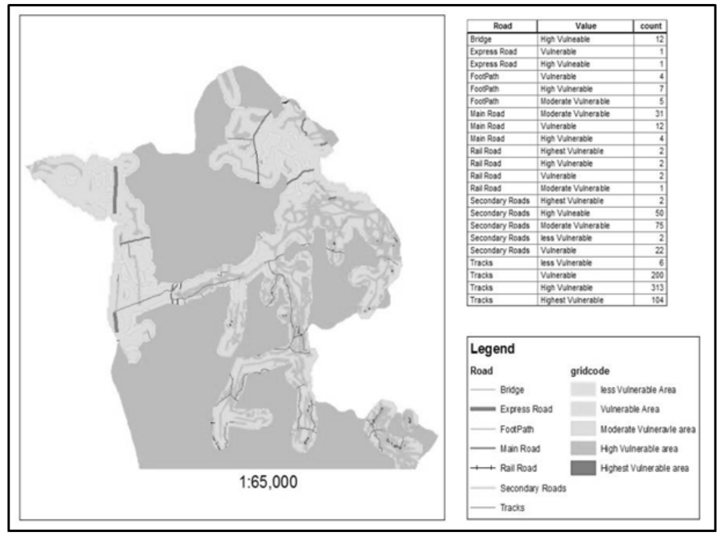

Figure 7 : Affecting Roads

Total 6279 buildings will be affected by the example flood. There will be 29 buildings which are located in the highest vulnerable zone and 1515 in high vulnerable area.

5 Conclusions

In conclusion, this Flood Mitigation Model can be applied for any area in any country as a simple task with a contour map, drainage network, road network, landuse categories, locations of the buildings, soil data and past flood data to pre estimate the Flood probability. This Model is referenced to the Ja-Ela Divisional Secretariat Division located in Gampaha District, Western province, Sri Lanka, which is always oppressed by the flood hazard during the rainy periods.
In accordance to the study thirty three (33) out of fifty seven (57) Grama Niladaari Divisions are prone to Flood hazard. Thudella west is the Garama Niladaari Division, which has been influenced as the most deleterious area in the Flood condition in May, 2016. Subsequently Dandugama, Indivitiya, Ekala, Kapuwatta and Weligampitiya North can be identified as high flood prone Garama Niladaari Divisions in Ja-Ela Secretariat Division.
Approximately 33% of the total Divisional Secretariat Division is influenced by the Flood of 220 mm Rainfall Intensity and 5 h Storm duration and 21% is influenced with 150 mm Rainfall Intensity Flood with the same Storm duration. It shows a 64% reduction of the vulnerable area with a 68% reduction of Rainfall Intensity.
As the model trot outs with the example Flood (Rainfall Intensity = 220 mm, Storm Duration = 5h), in the analysis with the land use type, the maximum effect is in the category of Home Gardens (37%) and Paddy lands (35%). The impacts on paddy lands are not much more important with respect to the agricultural background of the area, since the majority of the paddy lands are abounded.
In accordance to the model with the example Flood (Rainfall

Intensity = 220 mm, Storm Duration = 5h), all the watersheds are vulnerable for the Flood and the Watershed in Indiminna, Dolahena, Batagama and Bandigoda and the Watershed in Thudella, Dandugama, Dehiyagatha, Kanuwana and Weligampitiya are the most vulnerable to the flood hazard, considering the total vulnerable area.

In Ja-Ela Divisional Secretariat Division 847 Roads are influenced by the example Flood (Rainfall Intensity = 220 mm, Storm Duration = 5h), neglecting the expressways and the bridges. There are four high vulnerable main roads including, Ja-Ela – Ekala- Gampaha- Yakkala Road (81m), Pamunugama Road (112 m), Negambo Road (72 m) and Ragama – Mahabage Road(10 m), a footpath and a railroad (Negambo Railroad near Kapuwatta) and 427minor roads. Total 42 Main roads and 151 secondary roads will be vulnerable to flooding.

Total 6279 buildings are affected by the example flood (Rainfall Intensity = 220 mm, Storm Duration = 5h). There are 29 buildings which are located in the highest vulnerable zone and 1515 in high vulnerable area. That is better to relocate the 29 buildings in the highest flood vulnerable area.

In this study the variables for the soil condition is same since the entire area has same soil properties. When it goes to an area which has different soil types, the Coefficient of Runoff (K) and the coefficient c, will not be a constant.

Finally, this model can be concluded as a good approach to give a pre estimation of Flood condition, it will help to identify flood prone areas with respect to rainfall intensity, storm duration and soil condition.

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TABLE 17
Values of K

Type of catchment	Large	Small and steep
1. Rocky and impermeable	0·80 to 1·00	
2. Slightly permeable, bare	0·60 to 0·80	
3. Slightly permeable, partly cultivated or covered with vegetation	0·40 to 0·60	
4. Cultivated absorbent soil	0·30 to 0·40	
5. Sandy absorbent soil	0·20 to 0·30	
6. Heavy forest	0·10 to 0·20	

APPENDIXES

Appendix 1 : Values of K

TABLE 14

K.R.	C
0·6	0·0365
1·2	·0216
2·4	·0137
4·8	·0096
7·2	·0079
9·6	·0071
12·0	·0065
14·4	·0060
16·8	·0056
19·2	·0054

Appendix 2: c Values