STICHTING DELTARES

Accounting for Social Vulnerability in Flood Risk Assessment in Colombo, Sri Lanka

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1: Forward

1.1 Introduction

One of the world's great tragedies is that those who are the most vulnerable members of our population are also most often those who find themselves, through a combination of ill fortune and downward economic pressure, living in areas prone to natural disaster. A further tragedy is that these same people are often overlooked in the hard calculus of disaster impact planning and abatement. The proposition that one dollar of damage caused by disaster will impact the lives of a subsistence farmer and an oligarch in an equal manner is a falsehood, and helps enforces the underlying power structures which posited both individuals in such disparate positions in the first place. Under current Flood Impact Assessment strategies, damages are aggregated spatially and demographically, which is one way by which this narrative if furthered. Hence, it is the goal of this paper to give an overview of the work being produced in the fields of spatial economics and human geography which would see the inherent shortcomings in contemporary Flood Impact Assessment bettered and to produce a workable example in a GIS environment to showcase the practical applications thereof. This goal leads logically to the posing of the following research question:

(1) *What possible additions can be made to existing processes within flood risk assessment through the medium of GIS to meet an outcome which produces analysis which takes into due consideration relative Socioeconomic Status of often heterogeneous populations?*

As much as is possible, the new methods discussed will be integrated with the current workflows and conventions in place at the Water, Subsurface, and Infrastructure Research Institute Deltares, and as such, will interact with the problem through the lens of flood impact assessment, one of the primary subjects at the institution.

The report is structured as follows. In the first section, Background, the basic theoretical concepts of Flood Impact Assessment, as well as the specific tools which are being used currently at Deltares to implement them in practice will be given. Additionally, an assessment of these tools with respect the degree of the social equitability of their output will be given. In the second section, Novel GIS Analyses, two new tools to help achieve what the author of the report feels is a socially equitable outcome will be described. A new way to interactively visualize data, as well as a new manner by which to describe the direct, tangible damages of flooding which is both demographically and spatially explicit will be proposed. The report will then conclude with a section discussing the implications of the finding and results of the preceding sections, as well as an critique detailing the limitations hitherto.

2: Background

2.1 Flood Risk Assessment Strategies

Before the tools used by Deltares to describe the impact of flood damage can be discussed in any depth, the methodologies by which they arrive at the flood extent maps, which are crucial inputs for much of the geospatial analysis to come, will be briefly outlined. At its heart, predicting the physical extent of a flood event is a combination of the volume of water added to the system per unit of time, and the topography of the drainage area. The nature of the inputs does depend on the temporal scale of the flood prediction. Real time and medium range (7-10 days) flood predictions rely on the direct measurements of flood forcing meteorological events. The flood predictions made by Deltares and similar organizations which plan for flood mitigation strategies in the long term, as opposed to immediate response options, make what are referred to as Probabilistic Flood Risk Assessments (Dahm et al., 2013). This takes into account the year to year probability of forcing events ranging from near once in a century high or low input amounts to levels mimicking the mean inputs per year. And from there fabricates a range of scenarios with gradually decreasing return periods, beginning e.g. 2 years, and becoming gradually less likely. The forcing events taken into account in aggregate consist of expected annual sea level, discharge of local bodies of water, and projected volumes of precipitation. The result of this is a series of raster structure datasets showing the flood inundation levels of a catchment area or interconnected catchment areas with a corresponding return period measured in years. How expected amounts of annual damage are derived from the range of projections described under the theoretical framework of Probabilistic Flood Risk Assessment will be described in the following section (Dahm et al., 2016).

2.2 Flood Impact Assessment Tool

At this point, the first GIS tool used in the workflow associated with this project comes into action. The Flood Impact Assessment Tool, or FIAT, is the in house software at Deltares used to describe the economic consequences of flood events. However, this stage of the workflow departs from the strict probabilistic modelling techniques found in the meteorological and hydrological forecasting methods, and moves to an expected annual damage (EAD) figure instead. The reason for this is that to make effective policy recommendations, an average expected sum needs to be compared with the initial capital investment and upkeep costs of mitigation infrastructure and strategy investments. A dollar amount “saved” can be easily calculated by comparing the total investment costs over the lifetime of the investment and the Expected Annual Damage, this process is commonly referred to as a Cost Benefit Analysis.

Flood Inundation Maps with absolute occurrence rates mentioned in the above section are used as one of the inputs for FIAT, and are overlaid with a polygon file showing the built environment of the study area through the spatial positions of building footprints. In an ideal situation, the polygon file would accurately describe each and every building within an urban area, its primary use, its condition, and if applicable, the number of persons living there. Using such attribute data, amounts of damage can be calculated per raster cell by comparing the number of buildings affected to the amount of damage which can be maximally inflicted upon it. Maximum amounts of damage are calculated based on the aforementioned attribute data of building polygons. Damage Raster Maps for each probability are combined statistically into an Expected Annual Damage by overlaying the individual raster files while taking their probability in relation to one another into account (Slager and Wagenaar, 20xx).

2.3 Current Capabilities

FIAT’s ultimate output of an Expected Annual Damage Raster Map is what is most often used at Deltares for empirically supporting answers to Cost Benefit Analysis for clients in flood sensitive areas. What it leaves to be desired is a capability for a holistic and intersectional understanding of the economic impacts of floods. Spatial distribution of wealth in cities, especially in lower income countries, is heterogeneous in the extreme, which in turn causes sub-sections of populations with varying Socio Economic Status to experience aftermath of disasters differently (Cutter, 2008). Additionally, the data inputs, processes, and outputs are not immensely approachable for policy makers and stake holders who are unfamiliar with GIS and/or Hydrology.

As brief an overview as it is, the preceding sections prime the research question described in the introduction with a suitable degree background information so as to be answered in the context of current practices in flood risk and damage analysis. Exploring both the empirical techniques to describe the relative effects of economic flood impacts of an economically diverse urban living scape and methods to easily and effectively communicate such information will be the purpose of the remainder of this paper, and will hopefully answer the research questions successfully. As the primary project pertaining to flooding events, the case study of Colombo, Sri Lanka, will be used as a subject and example for the novel GIS products proposed below.

2.4 Case Study

Colombo is the largest city and financial capital of the island nation of Sri Lanka, with a metropolitan population of more than three quarters of a million people. The Metropolitan Colombo area has a high potential for harmful flood events due to its geographic position at the mouth of a monsoon fed river drainage system. This already substantial risk is aggravated by the rapid urban growth, coupled with unplanned patterns of human settlements and land use. In addition the increasing population and unplanned development have led to encroachment of canal reserves, reclamation of wet lands, and spread of settlements in to high flood hazard areas.

The consultation of Deltares has been focused on minimizing Colombo's exposure to flooding events by identifying areas which are likely to experience damage, and then recommending cost appropriate interventions. Standard best operating practice in these cases includes interventions such as "improving the drainage systems, creating extra storages, enlarging the conveyance and outfall capacities as well improvement to flood early warning, formulation and implementation of necessary policies for land use management, building control, etc." (Grehels, 2017) It is also essential to line up strategic support for implementation of the above mentioned strategies by the development agencies. What is sought to be accomplished through this essay is to apply a more nuanced identification method, one which takes into account the Socioeconomic Status of those affected, and to recommend a retargeting of interventions if the outcome is significantly different than the traditional method, which only takes into account the dollar amount at risk.

3: Novel GIS Analyses

3.1 3D Visualization

Effective communication with policy makers is imperative when researchers attempt to make their finding not only known, but understood. Within the field of scientific communication, the use of electronic media has become more and more widespread over the last 15 years (Feldman, 2001). Specifically, within the Spatial Sciences, new forms of communication have been developed to go beyond the standard cartographic representations of data. Examples of this include interactive geocoding, and real time navigation services (Sui, 2001). Studies conducted by Camara and Raper have proved the increased communicative efficacy of "new" Geospatial media. One of the examples sighted was of virtual reality, where users were able to interact with a GIS environment, so as to experience the same information as would be available on a map in a more engaging manner (Camara and Raper, 1999).

To that end, we decided that a novel method, in this instance 3D, would be beneficial in conveying our message to policy makers and other stake holders. This was mentioned as being an especially helpful tool in literature on the topic (Kling et al., 2000). Building on the virtual reality example above, this would add an additional layer of interaction for the user. This was accomplished by liaising with the Serious Games Department at Deltares in order to construct a virtual environment where our geospatial socioeconomic could be visualized in an engaging manner. Rendered in Unity Game Engine, a popular software suite used by game designers to produce games like "Pokémon Go!", this is the first impression which both policy makers and wider audiences will see regarding the spatial distribution of relative socioeconomic status and other attribute data across the urban space of Colombo. Interactive, different flooding scenarios can be seen overplayed with a 3D model of the built environment, in which different economic indicators can be chosen to be represented visually by colour on a building by building basis. Participants will give a more than cursory overview of the situation in the field of the geo-spatial overlap of flooding and Socioeconomic Status. The end product can be either downloaded as a complete entity, wherein users may boot the simulation on a personal computer, or it may be shown to a wider audience via screen capture software.

3.1.1 Method

1. Investigated Data provided by Sri Lankan Census Bureau, searched for data sets which would are at the most specific level of detail (GN District), and serves to further the inquiry of the research question, specifically what datasets would provide credible proxies for income and/or expenditure of residents.
2. The dataset containing information for the "Number of Households with Access to Electricity as their primary cooking fuel" was selected for a number of reasons. It was a linear, ratio variable which could be logically construed with the consumptive patterns of households. Cooking is a basic need, but cooking with electricity is not. Households with higher incomes would then choose to upgrade to a sufficient electricity subscription, and invest in appropriate equipment as one of their first purchases of luxury goods.
3. Data Cleaning and interpolation. The number of households with access to electricity as a primary means of cooking is cross referenced with the number of households per district to determine the proportion of households, and ergo residents (Derived through dividing number of dwellings by GND population), who have access to such resources. Also, there

were several districts for which no data had been recorded by the census bureau. A nearest neighbour sampling method was employed to make a continuous coverage of all GNDs with all polygons.

4. Building Footprint Dataset consolidation. At this point, a building footprint dataset was introduced as a layer to the GIS environment. Buildings which were residential in nature were selected, and exported as a separate layer. The Spatial Intersect toolbox was then used to ascribe the proportion of electricity using individuals to the individual building polygons from the GND layer. 3 Natural classes emerged here. Low adaptation to electric cooking >2%, middling adaptation 2-15%, and high adaptation, anything above 15%, most often in the homogenous range of 80% and upwards.
5. Further Class consolidation within Building Footprint dataset. One of the other economic attributes which was chosen to be shown in the 3D Environment was whether or not the buildings were part of an informal settlement, or "shanty". Achieved by consolidating the "remarks" category into 5 broad classes, one of which was shanties. This step was performed to correct for recording errors, i.e. spelling "shanty" as "santy", and for the sake of the visual clarity of the finished product.
6. 3-D Rendering in the Unity Game Engine. Building Polygons are rendered in LOD1, or LOD3 for several landmark sights, and are coloured on either a sliding scale, or categorical basis depending on the type of variable. Users are able to navigate the environment, and interactively change which of the datasets they wish to be seen. All of this is done on the fly.

3.1.2 Results

The 3-D environment was successfully completed, and made available to the entirety Deltares through the internal intranet system. This has afforded persons working both inside of the Colombo project and in other departments a look into data on the spatial distribution of income in the urban living scape of our case study city. Stemming from this, a greater appreciation for the work being undertaken within the larger inclusiveness movement within the company was achieved.

Also, a video of the environment has been shown in multiple workshops in the city of Colombo itself, to both policy makers and stake holders. This took place within the context of a presentation in combination with all of the existing work undertaken by the team working on the Colombo consultancy project, ranging from the flood damage raster maps mentioned in the FIAT section above, to the possible infrastructure and strategy interventions conceived by engineers and economists. The seriousness not only of the flood exposure to the city at large, a fact already keenly understood by the members of the local government, but also of the spatial confluence of flood damage and poverty. This will be described in greater detail in the following sections. Perhaps most tellingly, the financial representatives of the World Bank were impressed by the information presented in the environment. The importance of inclusiveness may have made an inroad in this instance, because not only were the decision making parties of the Colombo flood intervention case reached by this novel method of communication, but so were representatives of an organization which handles and bankrolls interventions around the world. Even if the significance were to be lost on local authorities, this product effectively made the case for the importance of inclusiveness on a larger scale. A copy of the 3D Environment may be requested by contacting the author.

3.2 Tabular and Cartographic of FIAT Post Processing Equity Weighting

Available data concerning the Expected Annual Damage projections for the Colombo study area is combined and reinterpreted with the spatial SES data visualized previously to reflect the variable effect of economic damage experienced by Colombo's residents. Tools already discussed in the Current Capabilities section were used as input in this process, and where subjected to novel post processing techniques in order to produce an analysis which would bring to the fore the interaction of spatial distributions of poverty and flood exposure. Spatial instance of economic deprivation were identified by looking at the consumptive data at the GND level, the most specific available, and this was then compared to national data of income distribution to find an approximation of income per GND. These approximations was then used as an input for equations which resulted in an "Equity Weight", which was used to modify the gross damage done to each GND. In principle, this allows us to quantify the damage done to each district in a way which takes SES into account, thus allowing a more accurate assessment of the impact of flood damages to areas which are heterogeneous in the economic capacity to overcome natural disasters.

3.2.1 Methods

<u>Initial Flood Impact Assessment</u>

1. A FIAT model was run for the Colombo Study area so that the primary Expected Annual Damage raster could be introduced into the project's workflow. Flood extent projections overplayed with the GND boundaries of Colombo, as well as an inset map of the study area's position within a broader geographic context can be seen in Appendix II.
2. Gross damage done to each GND was then calculated by running a Zonal Statistics analysis using the GND polygon layer and EAD raster layer. Cartographic representation of the result

may be found below in figure 1, alongside tabular output of the 5 highest damaged GN Districts, table 1.

<u>Identifying and Defining Heterogeneous Segments of Colombo's Population</u>

3. Deriving a spatial distribution of income in Colombo from the data available to us was the next step in the equity weighting process. The consumptive patterns described by the adoption rate of electric cooking equipment were broken into quintiles, and compared to the distribution of income in Sri Lanka as a whole. With a data concerning the income distribution of Sri Lanka, it is possible to show per quintile what the average income per capita is. The equation below shows how the average income for each quintile was derived.

$$CN^Q = (AN^C * Q_S)/Q_p$$

Where:

CN^Q is the Per Capita Quintile income

AN^C is the Aggregate Income of Colombo (constant)

Q_S is the Quintile share of income

Q_p is the Quintile Population (constant)

<u>Describing Flood Damages as a Function of Socioeconomic Status</u>

4. The total income for each GND was calculated by multiplying the population of each district (ii) by the average income for the SES class derived in the previous step. This information is then compared to the gross Expected Annual Damage from step 1, and damage as a percentage of total income can then be calculated. A choropleth map showing this in addition to the spatial distribution of income quintiles is to be found following the gross damage map below, figures 2 and 3.

$$AN^G = CN^Q * D^G * H$$

Where:

AN^G is the total income per GND

D^G is the population density of the GND of residents/household

H is the number of households

5. Seeing flood damage visualized via relative damage in proportion of income lost can be helpful to see how heavily a district is affected by projected Expected Annual Damage, but it is not the most effective option in this a CBA, because it does not allow us to see how much

damage saved in direct relation to SES. Hence, we calculate Equity Weights (EW) to modify the gross damage caused to each district as a function of its SES. EWs are calculated by looking at the relative utility of an additional unit of income, in this case 1000 Sri Lankan Rupees, normalized for relative SES. Marginal utility is calculated by equation iii below, which is then applied to an equation to calculate the equity weight of damage for each income group (iv). The equations are taken from the paper of Jarl Kind et al (2016). The results and equity weights for each income quintile can be seen below in table 2.

$$U(\delta \mathrm{Y}) = U(Y_1) - U(Y_0)$$

In Which Utility is Calculated By

$$U(Y) = \frac{Y^{1-\gamma}}{1-\gamma}$$

Where

$U(\delta \mathrm{Y})$ is the marginal utility of an additional unit of income

$U(Y_1)$ is the utility of average quintile income plus 1000 SLR

$U(Y_0)$ is the utility of average quintile income

γ is the elasticity of income (1.2)

iv. $\omega_{yi} = \frac{U(\delta Y)_Q}{U(\delta Y)_M}$

Where

ω_{yi} is the equity weight

$U(\delta Y)_Q$ is the quintile marginal utility of income

$U(\delta Y)_M$ is the median utility of income

6. EWs are then applied to gross Expected Annual Damage sums per GND to calculate Equity Weighted damage for each polygon. A map showing this spatial distribution would be redundant, because of figure 3, which shows damage as a proportion of income shows an identical distribution. But a map showing the difference between each district's Equity Weighted Expected Annual Damage and its Gross Expected Annual Damage is included to clarify the relationship between the two metrics, and concludes the series of maps below in figure 4. Continued within table 1, a modified ranking of most damages districts is offered, as well as their change in rank (if available) from the first portion.

3.2.2 Results

The end products of the Post-Processing of existing outputs described and illustrated in the previous section provides the user with an array of additional sets of data to influence decision making for proposed mitigation strategies. Social vulnerability is easily conveyed to the audience cartographically by mapping the proportion of lost income of districts projected to be victims of flood events (Figure 3). Furthermore, analytical capability is created by applying equity weights to Gross Expected Annual Damage (Figure 4) amounts for districts, showing the impact of flood damage to residents as a function of their Socio-Economic Status relative to other enumerations in the same study area. Competing mitigation strategy scenarios can then be compared in a cost benefit analysis not only with the total dollar amount by which they decrease Expected Annual Damage, but also the sum of equity weighted damage they prevent.

For the data used in this example, we would not expect to see a massive change in results between mitigation scenarios chosen, due to the fact that the majority of flood damage happens in districts within the bottom two income quintiles of the city. However, many of the competing strategies being considered (Deltares, 2016) do not target the most heavily affected regions of the city. Therefore, the true seriousness of this spatial combination seen by the reinforcement of the pattern portrayed by gross Expected Annual Damage when compared to equity weighted Expected Annual Damage is of grave importance. The fact that the majority of economically deprived residents, as spatially described by income quintiles, and the majority of flood related damage, described by gross Expected Annual Damage, are spatially highly correlated is an extremely worrying fact. In the maps below, it can be seen that a flood plain can be identified by observing the highly concentrated cluster of damaged neighbourhoods in the North of the map, and that a similar clustering of low income neighbourhoods can be observed in a corresponding zone on the following map. And finally, the degree to which damages are worsened by economic deprivation can be seen in the final map of the difference between gross and equity weighted Expected Annual Damage, hopefully conveys the seriousness of the situation in a suitably concrete manner. Making a socially equitable choice will be that much harder to avoid.

GND	EAD	GND	EWEAD	Change in Position
Megoda Kolonnawa	392721,4	Kittampahuwa	818878	+1
Kittampahuwa	353721	Kotuvila	814132	+1
Kotuvila	351671	Maha Buthgamuwa C	784108	+1
Maha Buthgamuwa C	338701,7	Megoda Kolonnawa	553934	-3
Welewatta	317099,4	Sedawatta	544895	N/A

Table 1: Rank Ordering of GNDs before and application of Equity Weights

Table 2: Equity Weight Tabulations

Q	Y0	Y1	UY0	UY1	U(δY)	EW
1	135942.7	136942.7	0.47022	0.46953	0.000689	2.315036
2	205690.4	206690.4	0.43284	0.43242	0.00042	1.410504
3	274129.2	275129.2	0.40868	0.40838	0.000298	1
4	384641.1	3856411	0.38191	0.38171	0.000198	0.666426
5	869322.5	870322.5	0.32444	0.32436	7.46E-05	0.250714

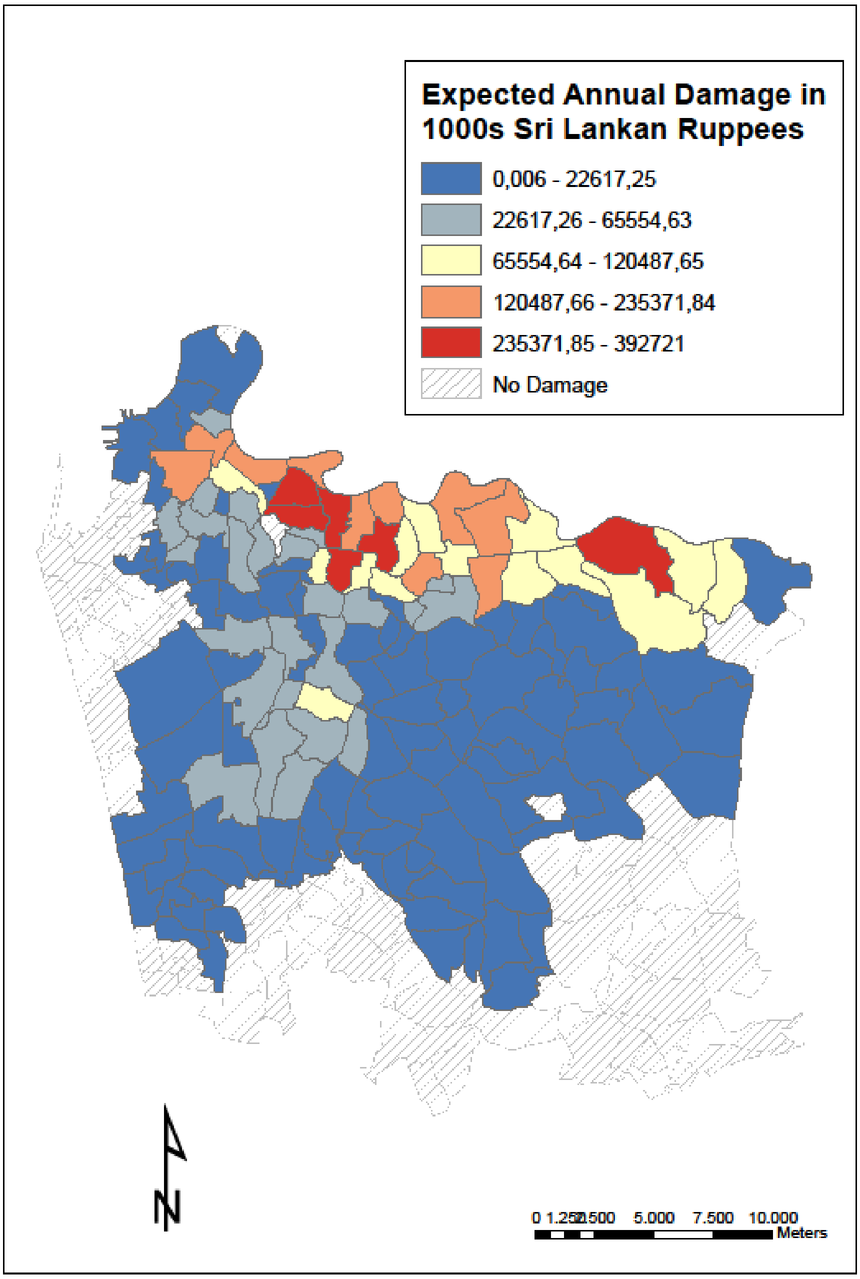
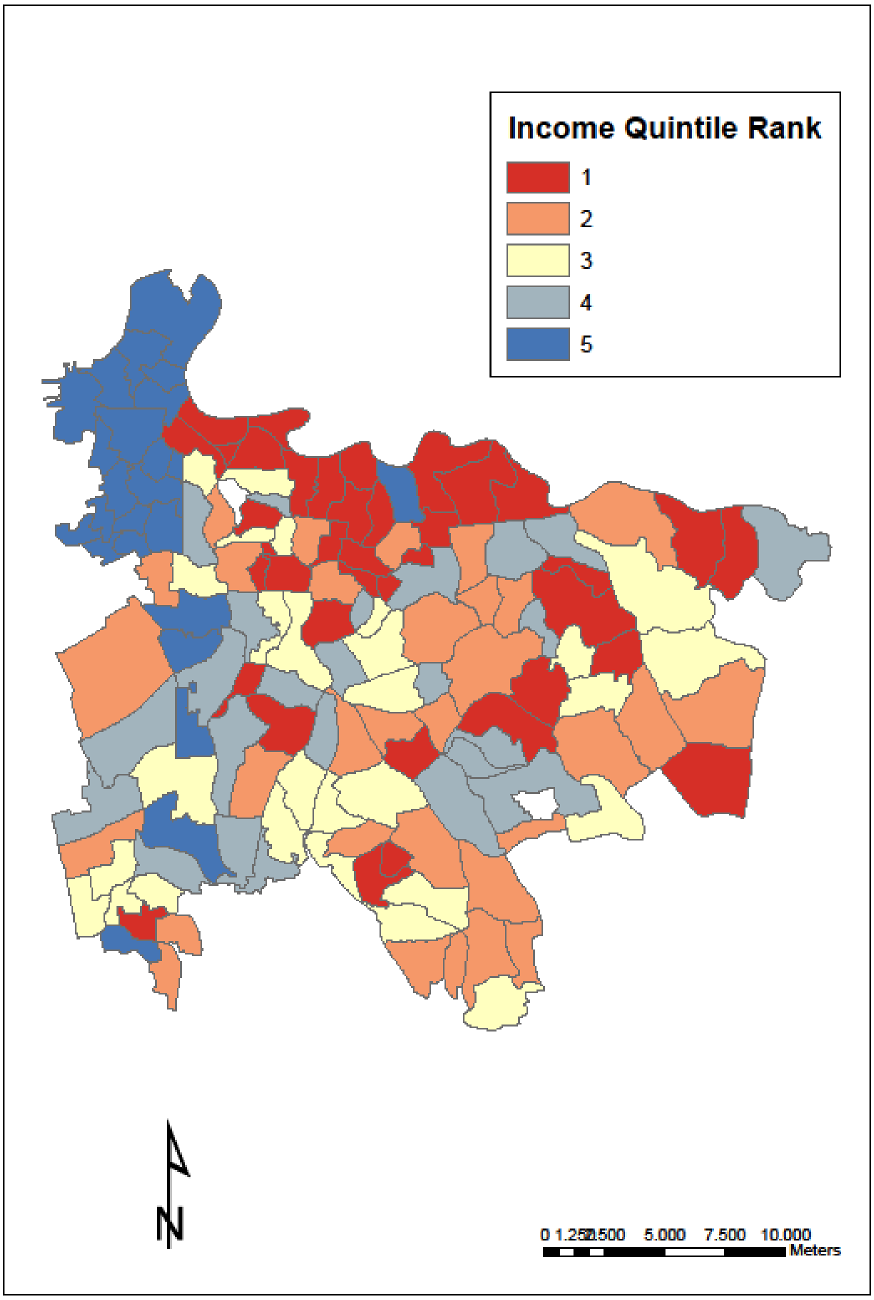


Figure 1: Expected Annual Damage Projected per Grama Niladari District



Income Quintile Rank Per Grama Niladari District

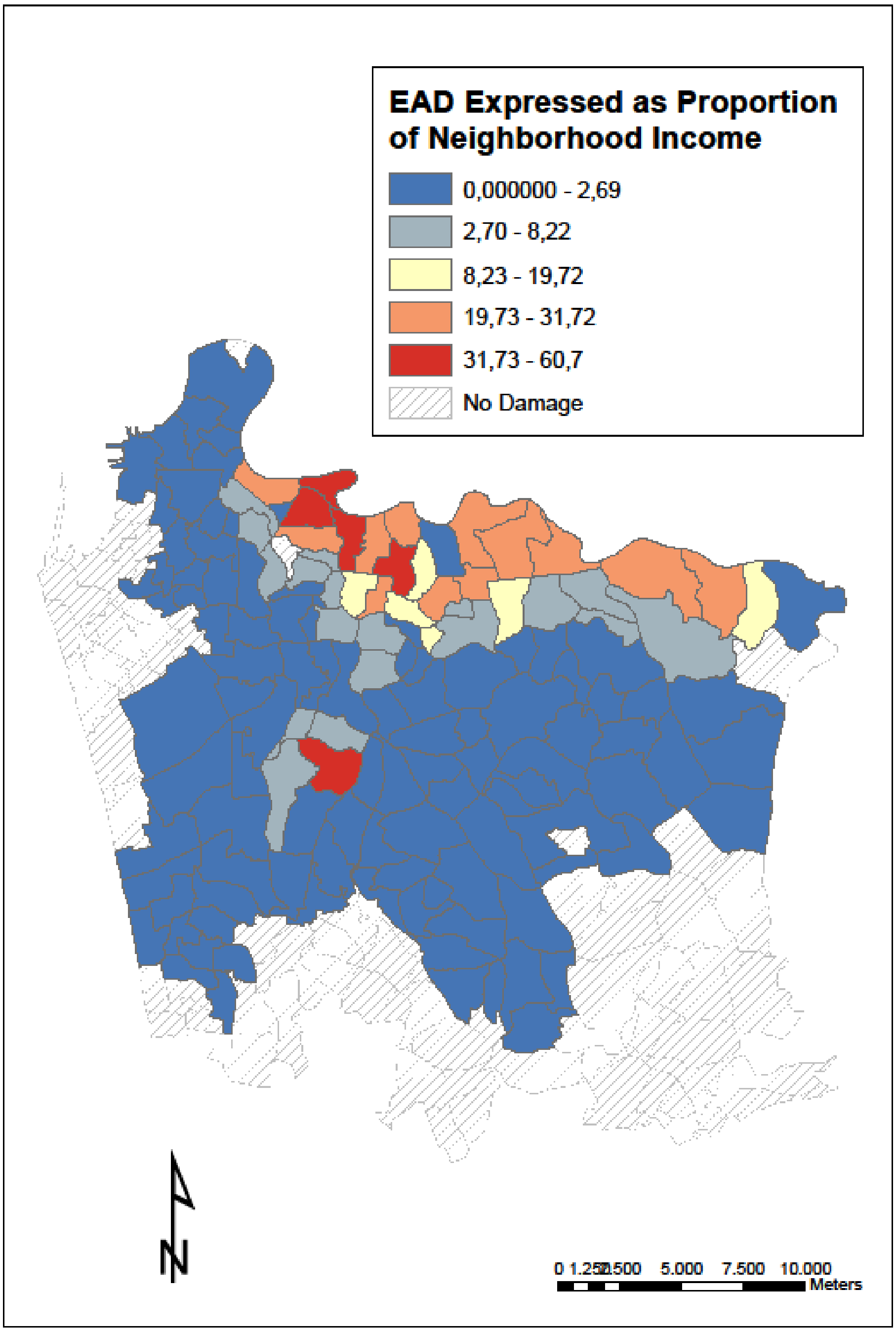


Figure 3: The Proportion of Grama Niladari

District Annual Income Projected to be Lost Due to Flooding

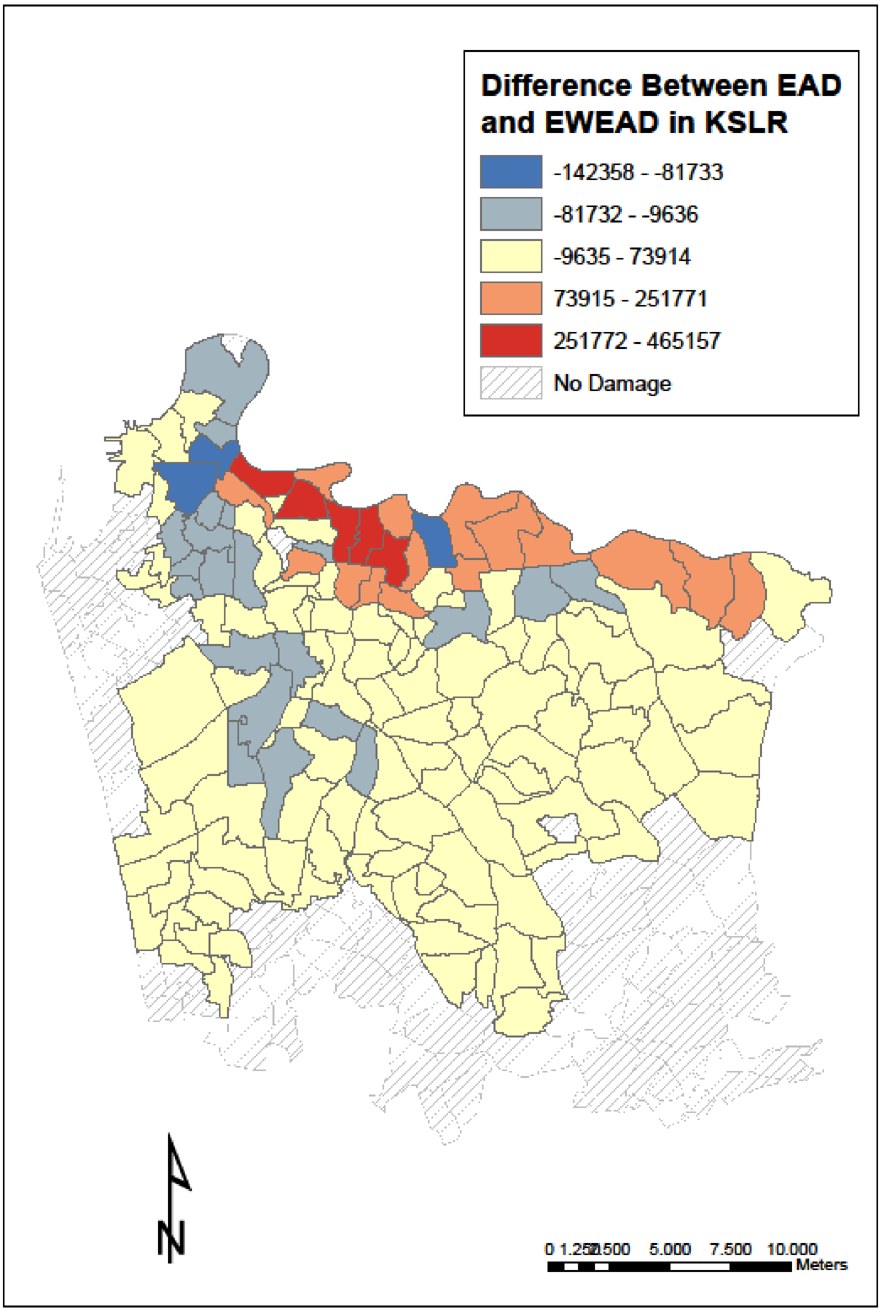


Figure 4: The Difference of 1000s of Sri Lankan Rupees Between Gross Estimated Annual Damage and Equity Weighted Estimated Annual Damage

4: Conclusion

4.1 Discussion

Following the research question “What possible additions can be made to existing processes within flood risk assessment through the medium of GIS to meet an outcome which produces analysis which takes into due consideration relative Socioeconomic Status of often heterogeneous populations?”, this section of the report will question exactly to what extent value has been added to Flood Impact Assessment capabilities of Deltares by the introduction of GIS analyses appended by this paper to the existing workflow. Beginning with the rendered 3D environment, value added can already be identified relatively early in the flood risk, damage, and mitigation projection process.

One of the most difficult tasks can be effectively conveying spatially referenced Socio Economic Data to persons in decision making positions regarding the manner by which the effects of natural disasters are addressed. This often falls to the city fathers or other local administrative officials in the absence of a strong, central disaster relief agency. And whilst a simple overlay of vulnerable locations and expected flood extents can show much of the same information, a more content rich and interactive environment will have a higher impact, and a greater chance of gaining traction not only with audiences of decision makers, but also ones with a wider variety of stakeholders. Following the propositions of Kling and McKlim, the 3D Environment constitutes a method appropriate to the situation to introduce an innovative way to convey spatial information, and therefore communicate with the audience more effectively. In this way, the seriousness of the spatially uneven impact of natural disasters can be effectively visualized and communicated.

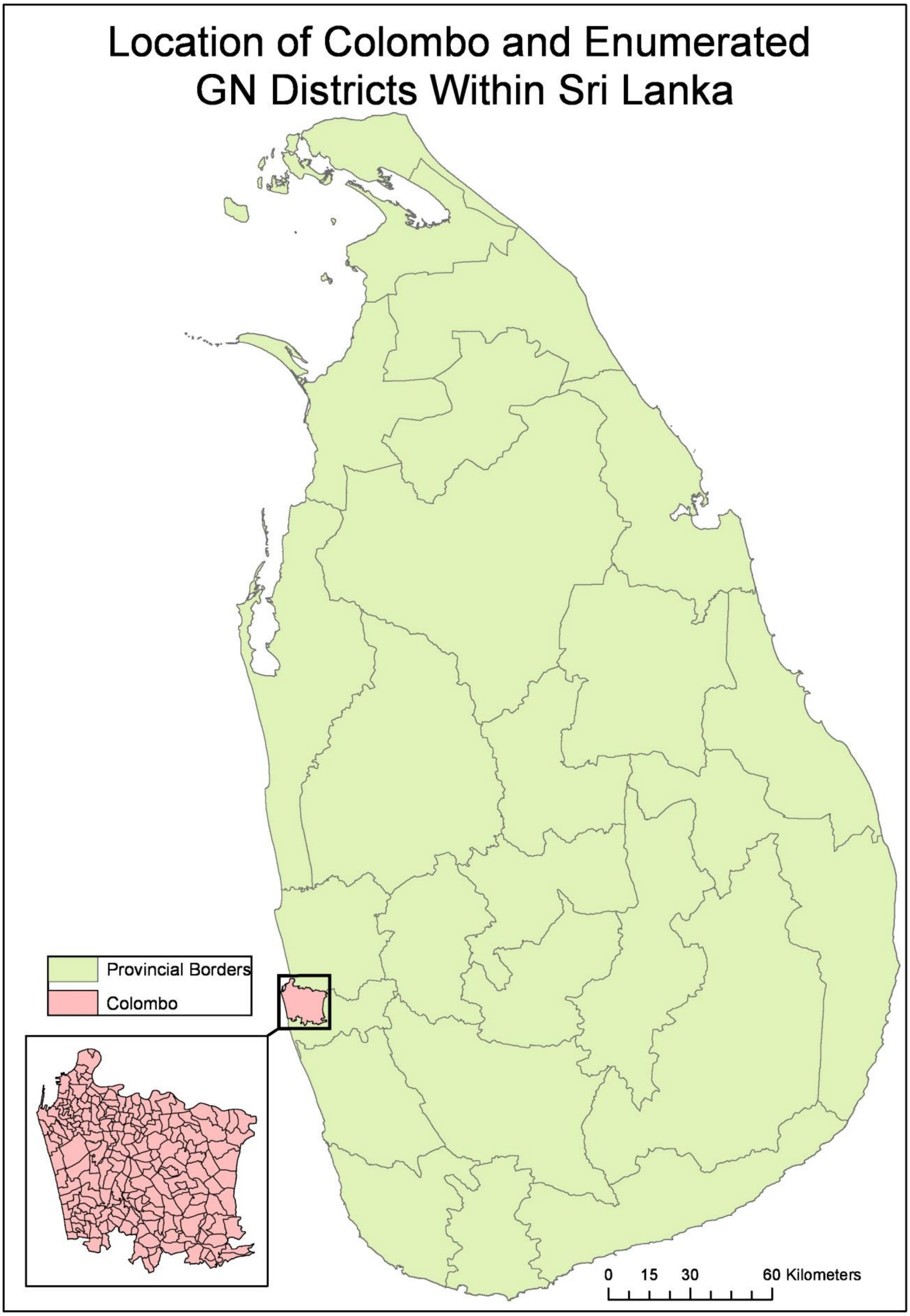
As seen and illustrated above in the case study of Colombo, economically deprived populations are concentrated in areas which are most prone to damage from floods (Figures x and y), an important pattern to recognize when looking into mitigation strategies. However, visualizing this information does not convey all of the information needed for policy recommendations. An empirical method grounded in the principals of welfare economics to interpret the financial dimension of flood damages adds on to improved visualization (Figure z). In Equity Weighting not only are patterns recognized, but future actions in the form of mitigation strategies are capable of being judged in a socially equitable manner. This was achieved by applying a methodology which adds an empirical tool to assess damage inflicted by natural disasters in a manner which takes into account the relative Socioeconomic Statuses of separate geographic enumerations within a study area into account. The end result of adding this to the toolkit of consultant and policy makers is to add the capability to judge an intervention, either strategic or infrastructure, by the projected damage that it saves, as well as its equity weighted counterpart.

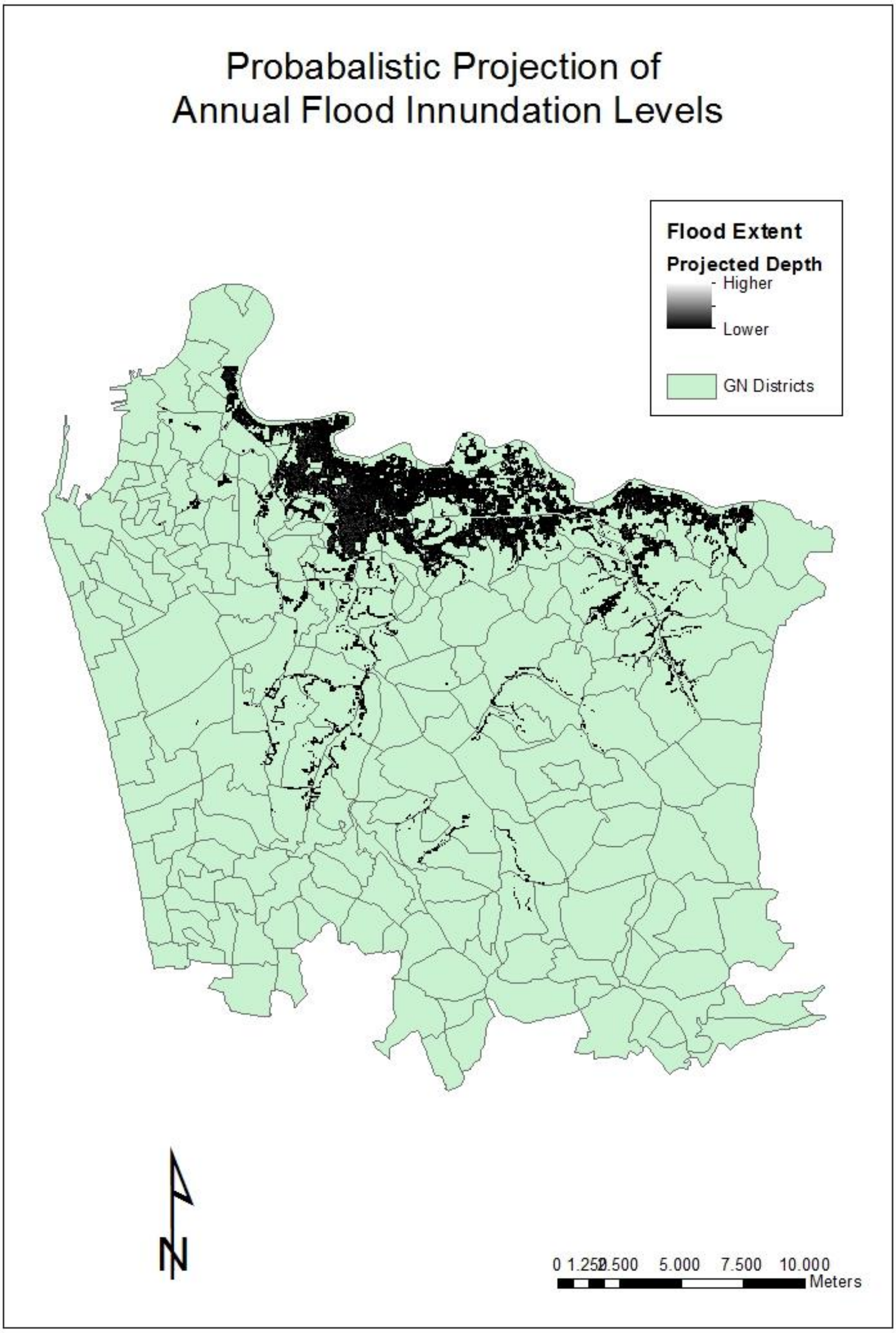
4.2 Limitations

There are naturally a number of limitations whenever geospatial analysis is conducted in an environment with less than perfect information. While often the case for any exercise outside of the hypothetical, is especially true for environments where data is either heavily interpolated, or otherwise inaccurate. The capitol of Sri Lanka is one such case. Beginning with the house footprint polygon dataset, discrepancies can be easily identified if the attribute data is observed in even cursory depth. One particularly glaring inaccuracy came across during the course of this analysis was the presence of "aggregated" polygons. For instance, some especially large polygons, which would be assumed to be commercial in nature, are actually denoted as something along the lines of "100 Houses" or the like. This proves problematic for several steps in the analysis where it is assumed that the polygons are each individual housing units, which may have accounted for up to 5% of units not being counted, and therefore misallocating population figures to specific GNDs.

Beyond inaccuracies in data collection, there were to a certain extent methodological failings in the design of the analysis. Environmental fallacy was especially detrimental to the integrity of the results, as at several moments, the characteristics of district level polygons were ascribed to individual enumerations, e.g. assuming the city of Sri Lanka has the same GDP per capita and GINI coefficient as the entirety of Sri Lanka. Finally, the largest and most spurious assumption employed by the author to perform the analysis was the prediction of income quintiles by census data of one particular hallmark of consumption. This departs greatly from the detailed required household income data proposed by Kind et al. when the mathematical concept of equity weighting was first proposed. Overall, the methods outlined and proposed herein can be applied to scenarios like Colombo which have a dearth of traditional household income data to allow a socially holistic assessment of the financial impact of flood, or any other disaster.

Appendix I


Location of Colombo and Enumerated GN Districts Within Sri Lanka
Provincial Borders
Colombo
0 15 30 60 Kilometers


Probabalistic Projection of
Annual Flood Innundation Levels
Flood Extent
Projected Depth
Higher
Lower
GN Districts
0 1.250 2.500 5.000 7.500 10.000
Meters
N

Works Cited

- Camara, A. S., and Raper, J., editors, 1999, Spatial Multimedia and Virtual Reality (London: Taylor & Francis).
- Cutter, Susan L., et al. "A place-based model for understanding community resilience to natural disasters." *Global environmental change* 18.4 (2008): 598-606.
- Dahm, Ruben., et al. "On Flood and Inundation Management of Ho Chi Mihn City, Vietnam" *International Council on Flood Resilience* 5.11 (2013)
- Dahm, Ruben., et al. "Downscaling GCM Data for Climate Change Impact Assessments on Rainfall: a Practical Application for the Brahmani-Baitarani River Basin" *Hydrology and Earth Systems Sciences* 15.1 (2016)
- Deltares., "Consultancy Services for Conducting a Detailed Flood Risk Assessment for Colombo Metropolitan Region" *Internal Publication* 12.1 (2016)
- Feldman, Penny Hollander, Pamela Nadash, and Michal Gursen. "Improving communication between researchers and policy makers in long-term care or, researchers are from Mars; policy makers are from Venus." *The Gerontologist* 41.3 (2001): 312-321.
- Gehrels, Hans (1 January 2017), "Protecting Colombo from Future Floods". Retrieved from https://www.deltares.nl/en/projects/protecting-colombo-against-future-floods/.
- Kind, Jarl., et al. "Accounting for Risk Aversion, Income Distribution and Social Welfare in Cost-Benefit Analysis for Flood Risk Management" *Advanced Review, Wiley*
- Kling, Rob, and Geoffrey McKim. "Not just a matter of time: Field differences and the shaping of electronic media in supporting scientific communication." *Journal of the American society for information science* 51.14 (2000): 1306-1320.
- Sui, Daniel Z., and Michael F. Goodchild. "GIS as media?." *International Journal of Geographical Information Science* 15.5 (2001): 387-390.