uOttawa

Evaluating Level of Heat Stress for Cycling, Walking and Running paths through GIS

Submitted to

Prof. Ahmad Jrade

CVG6000

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Submitted by

Farzaneh Farshad

Student ID: 300124641

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Overview

GIS has always been an integrated tool that could analyze the accessibility plans, incorporates accessibility measures, lots of travel-impedance measurement implements to evaluate the travel distance, time, or cost through various modes of travelling and different kind of interaction with data-processing, network analysis, spatial data management and spatial visualisation functions (Liu & Zhu, 2004). Therefore, extensive variety of urban planning, transportation planning, assessing efficiency of the existing networks and infrastructures can take advantage of GIS (Liu & Zhu, 2004). So, scientists and investigators has been using geographical information systems (GIS) technology for many years (Arentze et al., 1994).

GIS is used by developers and planners regularly to plan, analyze and depict the procedure of their plans. It gives a better perception and broad view of future to apply it to today's plans for planners to ease their decision-making progress.

Global trends of increasing extreme events and temperatures are only going to continue to drive up different types of health risks. Health impacts of climate change worldwide that affect almost everyone's health in some way is needed to be carried out. Geographical information systems (GIS), has shown its helps to cope with this. GIS software tools are helping with planning and meeting these demands. Using GIS software and its toolbox, help tasks perform more efficiently.

It has been proved that the existence and growth of cycling networks and walking trails enabled several individuals to have greater physical activity (Houde et al., 2018). However, convenient infrastructures are needed to help resident's safety stay active outdoors during high-heat events. To compensate the serious safety problems of cycling, especially when the average temperatures are creeping up due to climate change and the number of extreme heat days that has been started to be experienced by residents of most Canadian cities is rising this study aims to identify the level of heat stress that exist on pedestrians and cycling trails, and it will be a platform for planning future ‘shade corridors’ for pedestrians and cyclists.

1. Chapter 1- Introduction

1.1 General

Associated Health problems, sedentary life style, obesity, heart disease, respiratory disease, diabetes, cardiovascular disease, hypertension, etc. are increasing due to the car dependent cities and suburbs (Cervero & Duncan, 2003). Expansion of cycling and walking could help resolving the mentioned issues (Portland State University et al., 2008). One of critical fundament of public health and active transport policy which has been progressively identified is Cycling (Iseki & Tingstrom, 2014). Not only will it rise the physical activity but also is positively associated with environmental factors and reduction of carbon dioxide emissions (Fraser & Lock, 2011). Furthermore, reducing air pollution and widespread inactivity is achievable by decreasing transportation with vehicles and rising trips by walking or cycling (Woodcock et al., 2009). This helps reducing gas emission, traffic congestion and increases health benefits (Iseki & Tingstrom, 2014) which needs developing infrastructures. Moreover, considering the climate change has already begun to impact everyday lives, one aspect which should be invested on is to have more safe outdoor hours in terms of heat stress level. This study shows a methodology which can provide routes and path for walkers and cyclists with low heat stress through GIS approach which have been frequently used in planning, analyzing, identifying and estimating routs and different kinds of maps in this project. It is presumed by transportation planning analyses that usually travellers make decision of taking routes for cycling based on the effort and energy required (Iseki & Tingstrom, 2014). For example, streets and routs varies in elevation, however, street network used in spatial analysis typically does not contain this information which can influence the essential attempt and energy demanded for cycling. So, it can affect the decision maker to bike or not as well as the route to take (Iseki & Tingstrom, 2014).

1.2 Problem Statement

It is well known that average temperatures are creeping up due to climate change, but less apparent is the major leap at the extremes specifically the number of extreme heat days to be experienced by residents of most Canadian cities in the coming years. This effect increases the threat of heat stress on public health and decrease the outdoor safe hours to do exercise. This research project aims resident to have safer stay active outdoor hours during high-heat events by creating an integrated map through GIS approach that shows the heat stress level of 5 different trails for cycling that will be a guidance based on minimizing heat load (suitability map for cycling) because among the paths that are similar in terms of length cyclists, walkers and runners prefer choosing the routes that needs less physical effort that is caused by the slope or direct sun light.

1.3 Research Purpose

With this research, the prime aim is to establish an integrated map that shows the heat stress level of 5 sample routes for cycling, walking and running which can be a platform for other studies to cover the whole city of Ottawa and develop an application for travellers to make decision of taking routes for cycling based on the effort and the heat stress that they feel. It will be a guidance based on minimizing heat load (suitability map for cycling). It would be a transportation planning analyser for municipalities to have a new urban planning metric which can Identify existing, and planning future 'shade corridors' for pedestrians and cyclists by prioritize tree planting.

1.4 Future Benefits

Experts responding in this study were in substantial agreement that the positives of digital life will continue to outweigh the negatives. So, this study will bring benefits to the majority of North Americans who experience harms due to the growing extreme heat days which has effect on public health and decrease the outdoor safe hours to do exercise. So, the future benefits of this study offer:

1. planning analyses which travelers can make decision of taking routes for cycling based on that and the effort and energy required.
2. Identifying existing, and planning future ‘shade corridors’ for pedestrians and cyclists by prioritize tree planting.
3. May lead to a new urban planning metrics.
4. May be a platform to stablish an AI-powered application that helps the residence in decision making of taking travelling route based on different factors such as temperature, climate condition, slope, distance, shaded areas, etc.
5. The app would eventually be distributed as one of the City of Ottawa’s freely available applications. It would allow residents to quickly receive recommendation about which route is currently the ideal based on their feature preference such as weather, temperature, slope, etc.

1.5 Summary

Manufacturing and economic growth addition to the fast urban population increase in over the global cities is causing a warmer internal core compare to the around natural landscape (Sultana & Satyanarayana, 2019). The problem is that car-centric mobility plans causes physical inactivity, greenhouse gas emissions, high levels of air pollution, high levels of noise pollution, traffic incidents with injury, space scarcity and last but not least disappearance of natural outdoor environments and eco-systems. Promoting a mode-shift to cycling is promising strategies to overcome mentioned issues: it provides transport, increase physical activity levels and the bicycle is a non-emitting mode of transport. However, well-designed and safe infrastructure is needed to promote a mode shift to cycling. This study aims to assess how an integrated map of different features that have influence on residence physical activity such as temperature, slope, etc. might alter the risk of being affected by heat stress level and help travellers making decision of taking travelling route.

2. Chapter 2- Literature review

2.1 Introduction

Reviewing the literature of travel and transportation behavior clarify that commuters think and choose where, when, and how to travel by applying the concept of generalized costs and effort.

One of the sustainable and environmentally friendly mode of transportation that has been recently defined is “bike planning” which not only is an exercise, but also it decreases the risk of health issues. Cycling is growingly identified as an essential parameter of public health recommendations and active transport policy. health benefits through increasing physical activity is achievable by decreasing transportation with vehicle and develop walking and cycling trails and infrastructures.

In view of this, GIS can play a key role in conducting a spatial analysis and providing maps of cycling and identify suitable areas for cycling. Since GIS have been used frequently to study and estimating the bike route, bike demand (heat map), and bikesheds, it seems that combining spatial data with cycling planning is not something new but the reality is that it is still demanded due its limitations. Recently, GIS has been widely used to define, study and evaluate pathways and trails, bicycle networks and network planning incorporating topographical data, surrounding environmental data and infrastructures. Many elements and aspects are involved in decision made by walker, runner and cyclists about their choice of route and time including topography, climate, presence of bicycle facilities, traffic conditions, transportation alternatives and cycling infrastructures (Dill & Carr, 2003). Adverse circumstances such as sharp slopes in topography, hostile weather such as rain, snow and high temperature and traffic congestion need more try from walkers and cyclists to shuttle a certain path (Fraser & Lock, 2011). Since most travellers wish to lessen energy usage, selecting most suitable routes for cycling in terms of climate, presence of bicycle facilities, traffic conditions, hilly topography, shady areas and temperature is important specially in heat events in summer. Between similar distance routes cyclists tend choosing the path that needs less physical activity that will be caused by the sharp slope and less amount of sweating because of the direct sun light. So, using the GIS planners can easily show the impact of different variables. Therefore, ArcGIS is used as one of the powerful GIS software for this research project.

2.2 Topography

Previous studies show that usually people tries to reduce their travel time and travel length which are common features that is being considered in GIS analysis. Many factors in surrounded environment influence those travellers by cycling and walking. Abundance and variety of facilities, design of cycling and walking network, pedestrian friendly pathways and land use impact the physical distance commuters prefer to take (Cervero & Kockelman, 1997). Unwilling condition in topography (e.g. sharp slopes) needs much more work from cyclists and walkers to shuttle within the same path, and therefore it will rise travel impedance (Parkin et al., 2007). It is believed that within this hypothesis a traveller is anticipated to choose the shortest way of cycling, walking or running but the point is that usually GIS analysis does not consider the terrain, elevation and needed effort related to various degrees of street slope to commute. In some cases, the traveller might prefer to pick a longer route instead of tasking shorter one with sharper slope. Considering that physical environment is one of the most affecting elements in cyclist decision making. Souleyrette et al, (1996) found that ‘‘mountainous topography’’ or ‘‘hilly or rolling topography’’ are impactful in deciding the biking path. Moreover, significantly slope directing the bicyclist determination of choosing their route more than other constants (Cervero & Duncan, 2003). (Yamashita et al., 1999) import a Digital Terrain Model (DEM) in GIS to calculate the slope values as an attribute to be applied on road segments across the city. Then they categorized the slope in four categories: 1) 0.0 to 3.0%, 2) 3.1 to 6.0%, 3) 6.1 to 8.0%, and 4) greater than 8.0%. These categories then were attached to each part of the road across the study zone using the Grid Analysis MGE (Modular GIS Environment) Module. Then, they evaluated the length attribute of the road links based on planar distance and the slope and used the MGE Network Analysis module to identify optimal bike routes between two points. Their approach has the advantage of creating a citywide street network dataset with slope data.

Winters et al. (2010) integrated two topographical measures including “hilliness” and “steepness,” through using 30-meter resolution DEM into their project GIS analysis. These variables were calculated to be used in three spatial zones per trip including route, origin and destination.

Winters et al. (2010) assessed “Hilliness” based on the standard deviation of the elevation for specific points inside each of three buffered zones per bicycle trip: trip origin, route corridor, and destination. Then they assessed “Steepness” specifically for the route zone, based on the proportion of segments sharper than 5% along the total way after dividing each street segment every 100 meters. “Steepness” values were allocated on each trail, rather than for every segment in the road networks.

Walkscore.com website published the ranking of the most bicycle friendly cities in 2012 in the US accompanying with an index that weighs hilliness among three other equally weighted components. “Hilliness” was defined based on the sharpest grade in a 200-meter radius. A citywide index showing the bicycle friendly neighborhoods within a city in the form of a heat map was shown in the result. However, it was unclear that the topography was counted in the methodology as a feature to define traveller sheds that the web site generates. All of these GIS approaches which were reviewed here has a mutual limitation which was dependency on the DEM files and the hypothesis that trails elevation is exactly as same as natural terrain topography.

Therefore, since studies took topography, terrain and street slope into consideration in this study we will develop a method to take slope as well as other features into account that make difference into a GIS analysis of cycling network result.

2.3 Shade

Heat stress is a daily threat to individuals during summer and can cause morbidity and mortality (Stone et al., 2010). Excessive solar exposure can cause inconvenient and it could be seriously harmful for individuals especially the vulnerable group during summer (Brash et al., 1991). The main factor of feeling heat stress in human body is sunlight exposure (Lo et al., 2019). To help residence with reducing the possible risks caused by sunlight preventing too much sunlight exposure should be considered. Urban pathways are public places that holds lots of public life and their design impact human outdoor sunlight exposure directly. Understanding the general street design, as well as the elements of streets that affect residence including the spatiotemporal distribution of sunlight, tree canopies and shaded areas, would be useful to expand and formulate methods to protect people from too much outdoor sunlight exposure. One of the most proper ways to decrees the urban heat island effect is developing urban green spaces which provide comfort zone to the nearby residents (Aram et al., 2019). Furthermore, urban green spaces can impact the neighbour areas with cooling effect which its intensity and density plays a major role in this phenomenon (Aram et al., 2019).

Rays of sun reaching pathways is affected by street trees and buildings. Therefore, Shaded aligned streets and public passageways is anticipated to lower outdoor thermal discomfort (Middel et al., 2016). To have attractive, accessible, well designed and pedestrian friendly pathways, shaded areas plays an essential role (Middel et al., 2016). Not to mention that this fact is called Urban Green Space (UGS) cooling effect which is described as the impact that urban green areas have on neighbouring areas and it is an adequate way to decrease the Heat Island Effect (HIE) (Aram et al., 2019). The effectiveness of this phenomenon (UGE) has been measured through filed measurements, scale models, and thermal remote sensing, and computer simulation (Farhadi et al., 2019).

So, planting trees, vegetation, and lawns in various range, size and level like parks, forests and green roofs will help within this purpose. It has been already revealed that “green infrastructure” will decrease the HIE (Sodoudi et al., 2014) while small vegetation areas has less effect than urban parks in cooling urban areas (Aram et al., 2019).

2.4 Heat Island Effect (HIE)

Many remarkable human health hazards such as gasping and heart disease are frequent due to Climate change (Oudin Åström et al., 2013). Indeed, fatalities during summer is the result of intense heat waves which has collision with the physical health problems including respiratory and cardiovascular issues, "elderly and limit access to resources" (Poumadère et al., 2005). Plausible vulnerability, disease and mortality are supposed to rise because of the heat excess and trapped emissions in metropolitan areas due to the human activities and consuming fossil fuels (Lo et al., 2019). Population growth and economic and industrial changes are the main reason that cities are generating warmer weather compare to the neighbour and suburb areas where benefited more from green landscapes (Sultana & Satyanarayana, 2019).

Because of the inequality between the natural landscapes and constructed surfaces, the heat is augmented by "urban landscapes" which is called Heat Island Effect (HIE) (Shandas et al., 2019). This phenomenon is caused by various reasons including the physical characteristic of materials that are used in urban areas such as building surfaces and the pathways' cover, land use, high rises that affect air movement and lack of urban green spaces (Giridharan & Emmanuel, 2018). This event is also the effect of expanding human population and rising in rate of consuming energy (Mirzaei, 2015). Temperature mean rise in summertime is expected to happen with increased frequency of days with extremely high temperature (Houde et al., 2018). HIE is the gathered hot air because of the high density of built-up areas (Sodoudi et al., 2014). Building high rises and development in urban areas causes absorbing heat during the day and creating high temperature differences between urban and rural areas. Brigman et al. (1995) believe that the climate change is influenced by development in urban areas in five main ways:

1) By replacing the previous road surface (grass, soil and trees) with asphalt, concrete and glass
2) By replacing the rounded shapes of trees and bushes with blocky, angular buildings and towers

3) By releasing extra artificial heat from buildings, air conditioners, industry and automobiles

4) By efficiently disposing of precipitation in drains, sewers and gutters, preventing surface infiltration and

5) By emitting contaminants from a wide range of sources, which, with resultant chemical reactions, can create an unpleasant urban atmosphere.

The temperature can alter up to 10˚C in reach of a metropolitan area (Shandas et al., 2019). Commonly, there is a strong correlation with greenery, green canopies, trees and neighbourhood to the water with lower temperature in urban areas (Aram et al., 2019). (Hoffman et al., 2020) believes that not only there is a strong relation between the lack of tree covered areas and historically underserved urban areas, at the national and regional scales, but also HIE is not only influenced by tree covers because using different materials within varying urban typologies also amplifies temperatures. He mentioned that areas with broad physical infrastructure, including residential complexes, railway terminals, industrial or manufacturing sites, and in vicinity of large business centers are experiencing greater heat effect.

2.5 Summary

summertime heat waves have extremes impact on human health than any other extreme weather with vulnerable people like elders being most at risk. However, it is broadly proved today that cycling network paths encourage the feeling of safety while using bicycle for both practical and transportation purposes (Houde et al., 2018). Although, there is a positive relation between the cycling infrastructures and the level of utility, many other features and criteria are involved in decision making by cyclists about the trail that they choose such as weather, topography, climate condition, presence of bicycle facilities, shaded areas, traffic conditions, transportation alternatives and cycling infrastructures (Dill & Carr, 2003). A threat that should be considered is heat stress impact individuals during summer which may end up morbidity and mortality (Stone et al., 2010). Vulnerability, disease and mortality are expected to rise since the heat excess and emissions trap in urban areas caused by industrial and urban activities and consuming fuels (Lo et al., 2019). Reluctant condition in topography including steep slopes needs much more work from cyclists and walkers to travel, and that is why it will rise travel effort (Parkin et al., 2007). Between similar routes in terms of length travellers has willing to select the route with relatively less effort in terms of physical activity due to the sharp slope and less sweating because of the direct sun radiation. Few studies took topography, terrain and street slope, temperature, heat island effect, shaded areas and tree canopies into consideration to provide a solution to solve this issue. So, in this study we develop a method to take these criteria into consideration.

3. Chapter 3- Methodology

3.1 Introduction

Since most travellers tend to decrease their energy usage while they are cycling, selecting most suitable routes for them in terms of climate, hilly topography, shady areas and temperature is important specially in heat events in summer. Different features impact the heat stress level in human body while doing cyclin or walking including the coverage percent of shade of buildings and trees on the route, the slope which mean the more slope, the more activity and feeling hot, vicinity to the rivers, canals, lakes, mitigation of urban HIE, etc. Appropriate areas for cycling, walking and running can be identified with maps in which spatial analysis such as resident demographics, land use, street types, and availability of bike facilities and transit services has been applied (Iseki & Tingstrom, 2014). GIS maps for each feature including landsat8 thermal maps, Slope maps, canopy maps, etc., accelerate evaluating each criteria impact on the heat stress level that someone feels while cycling. In other word using Index Overlay Method all the criteria and data can be integrated after being analysed and processed to be classified and weighted which ends up in Suitability map for cycling in terms of heat load.

3.2 Suitability Analysis

Geographical information systems can help to aid in decision making in a variety of ways one of which is Suitability Analysis. Suitability analysis is usually applied to support decision making in planning processes, such as environmental planning. To weigh different options of a decision based on certain properties and valuations, a range of mathematical calculations are applied. Often, the goal is to find the most suitable spot for a certain object. Suitability Analysis enables user to characterize, modify, compare, and grade studying sites based on how closely they join to criteria that you select and define. The combination of various criteria leads to a solution. Intersection of different levels of rasters and data is done in GIS to produce such a suitability analysis. The idea of suitability analysis explains the exploration for the locations and areas characterized by a combination of certain features. Usually, suitability map is extracted from suitability analysis which shows areas and locations that are ideal for a certain usage in form of thematic map (e.g. Cycling Suitability Map in terms of Heat Load). In figure1 retrieved from http://www.gitta.info/Suitability/en/html/WeightOverla_learningObject1.html it is shown that the suitability map can be in form of negative modification which is risk map that shows the area that are under certain hazard or risk of an event based on the defined properties (e.g. Heat Stress Map for cycling).

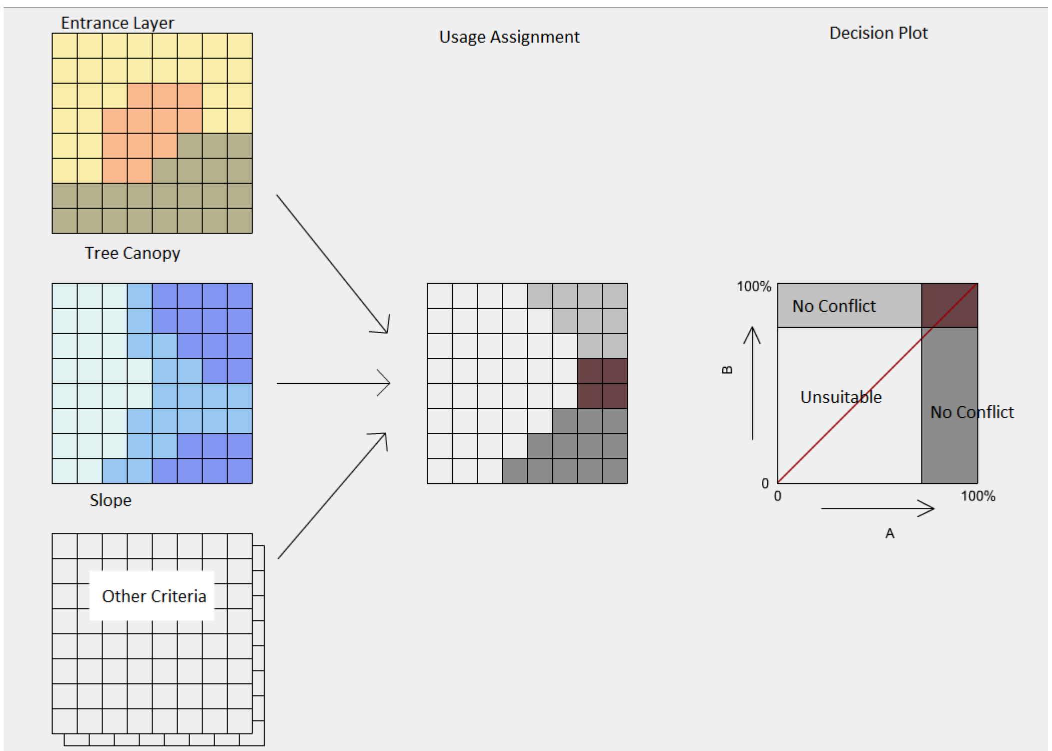

Figure 1- example of the result of a suitability analysis

3.3 Index Overlay Method

In (*Understanding Overlay Analysis—Help | Documentation*) it is explained that to do the optimal site selection or suitability modeling overlay analysis is one of the most common methodologies is being applied in GIS. To make an integrated analysis overlay is an approach for applying a common scale of values to various and different inputs. Moreover, it is a standard GIS analysis approach that is usually applied to deal with multicriteria issues like site-suitability. Weighted overlay is used when several criteria of different emphasis should be studied to achieve at a final decision.

While this project is looking for an integrated map which shows the ideal route out of the 5 sample routes, suitability models determine the best or most desirable locations for a specific event. Overlay analysis needs many different factors to be examined and analyzed. This data is available in various rasters with diverse value scales. So, a raster of land slope (degree) cannot be added to a raster of temperature and obtain a relevant and valid result. Also, the features in analysis may not be equally important. Even within a single raster, values must be prioritized. Some values in a singular raster may be perfect for the project objectives (e.g. slopes of 0 to 5 degrees), while others may be satisfying, others bad, and still others undesirable. In overlay analysis, it is valuable to set up the connection of all the input features together to determine the ideal locations that fits to the objectives of the model. For example, when the input layers weighted properly, they can be added together in an additive weighted overlay model. In this integration process, it is supposed that the more desirable the factors, the more ideal the location will be. Therefore, the higher the value on the resulting output raster, the more favourable the location will be. So, in most overlay analysis and suitability models, determining the best locations for the event that is being looked for are modeling is the final goal. The last step in the modeling is to inspect the results. Do the potential ideal locations sensibly meet the criteria? It may be useful to find the second and third suitable sites determined by the model.

Equation (3.1) was used for integration of factor maps using index overlay method.

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \qquad (3.1)$$

Where:

Wi= the weight of each factor map

Sij= each spatial class weight of each factor map

S= the spatial unit value in output map

Each class of map is given a different score, allowing for a more flexible weighting system. Score tables and the map weights can be adjusted to reflect the judgment of an expert in the domain of the application under consideration.

Fallowing process is used in ArcGIS to apply Index Overlay to get a suitability analysis:

- Each raster layer is assigned a weight in the suitability analysis
- Values in the rasters are reclassified to a common suitability scale
- Raster layers are overlayed, multiplying each raster cell's suitability value by its layer weight and totaling the values to derive a suitability value.
- These values are written to new cells in an output layer
- The symbology in the output layer is based on these values

3.4 Sample Routes

Planning routes from a start point to destination includes determining a variety of route options that provide efficiency while keeping utility (Brunyé et al., 2015). The action of selecting between route alternatives engages the demand of various trail selection criteria (Golledge, 1995). Usually, "route planners" apply various certain plans and approaches to select between different routes. It includes route length, time duration to pass that path, route efficiency (considering difficulty, density, traffic, weather, topography, slope), and utilitarian preferences (e.g., landscape, view, visiting a particular location along the way) (Brunyé et al., 2015). Approaches are also include choosing straight rather than bending routes “leaving an origin”, choosing typically trails that are going to south instead of north, and prevent choosing routes that has of complicated topography (Brunyé et al., 2015). Between equal-length routes individuals tend to select the route with relatively less effort in terms of physical activity due to the sharp slope and sweating because of the direct sun. For this study, routes were tried to be selected based on the random topography and slope, diverse direction to the North-South and East-West, not being more than 10 km, diverse in terms of shaded areas, divers in terms of locating in the city center and suburb to consider heat island effect by the experts at City of Ottawa as it is shown in the figures below (figure2 to figure6) :

Route 1: DAZÉ ST TO 3421-3419 OTTAWA 32

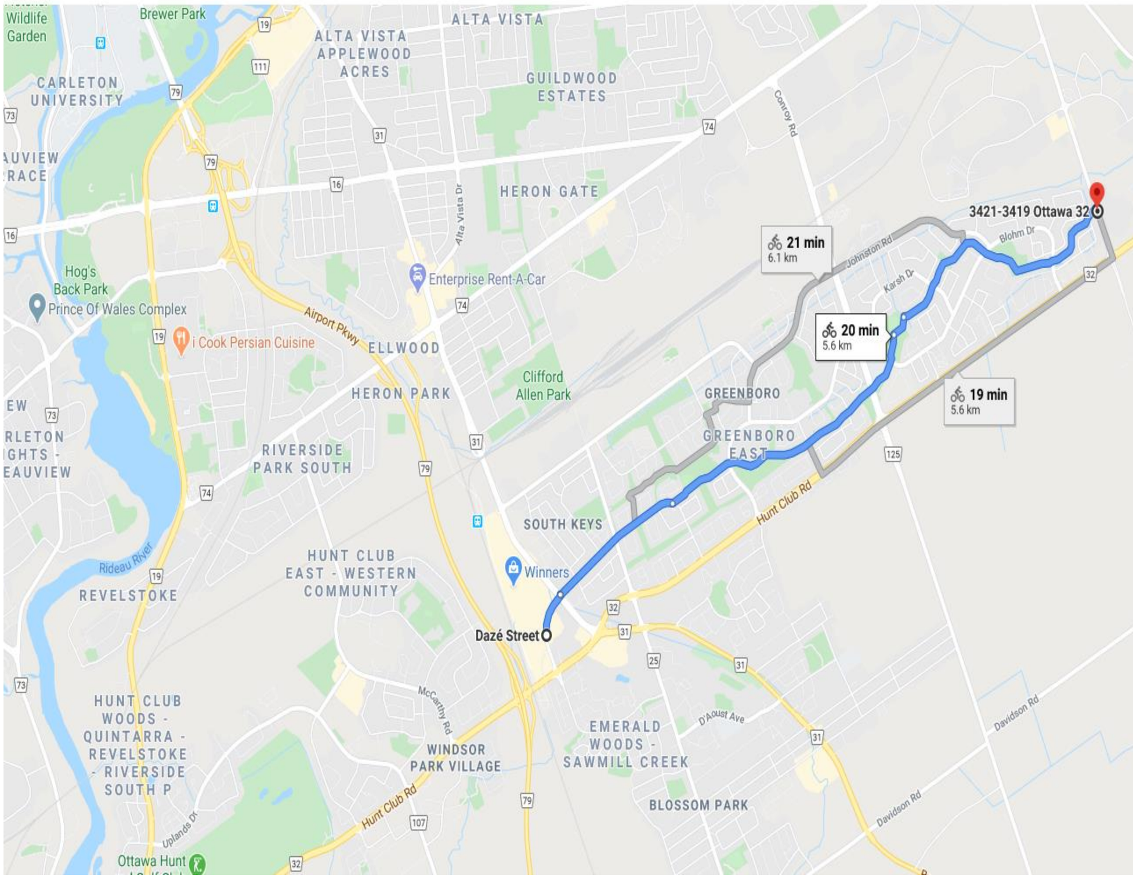

Figure 2-Sample Route 1

Route 2: ALBERT ST. TO ST. LAURENT / HEMLOCK

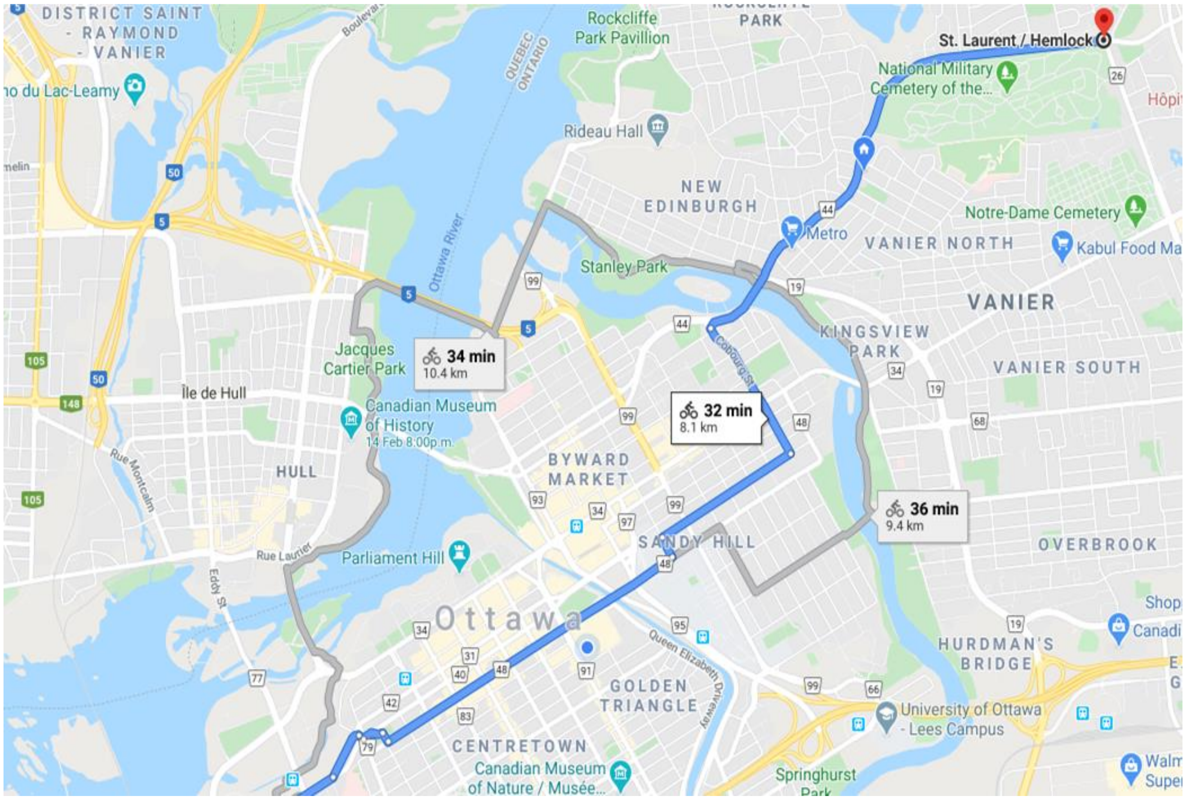

Figure 3- Sample route 2

Route 3: CONSTELLATION Dr. To WESTBRO STATION LIVING

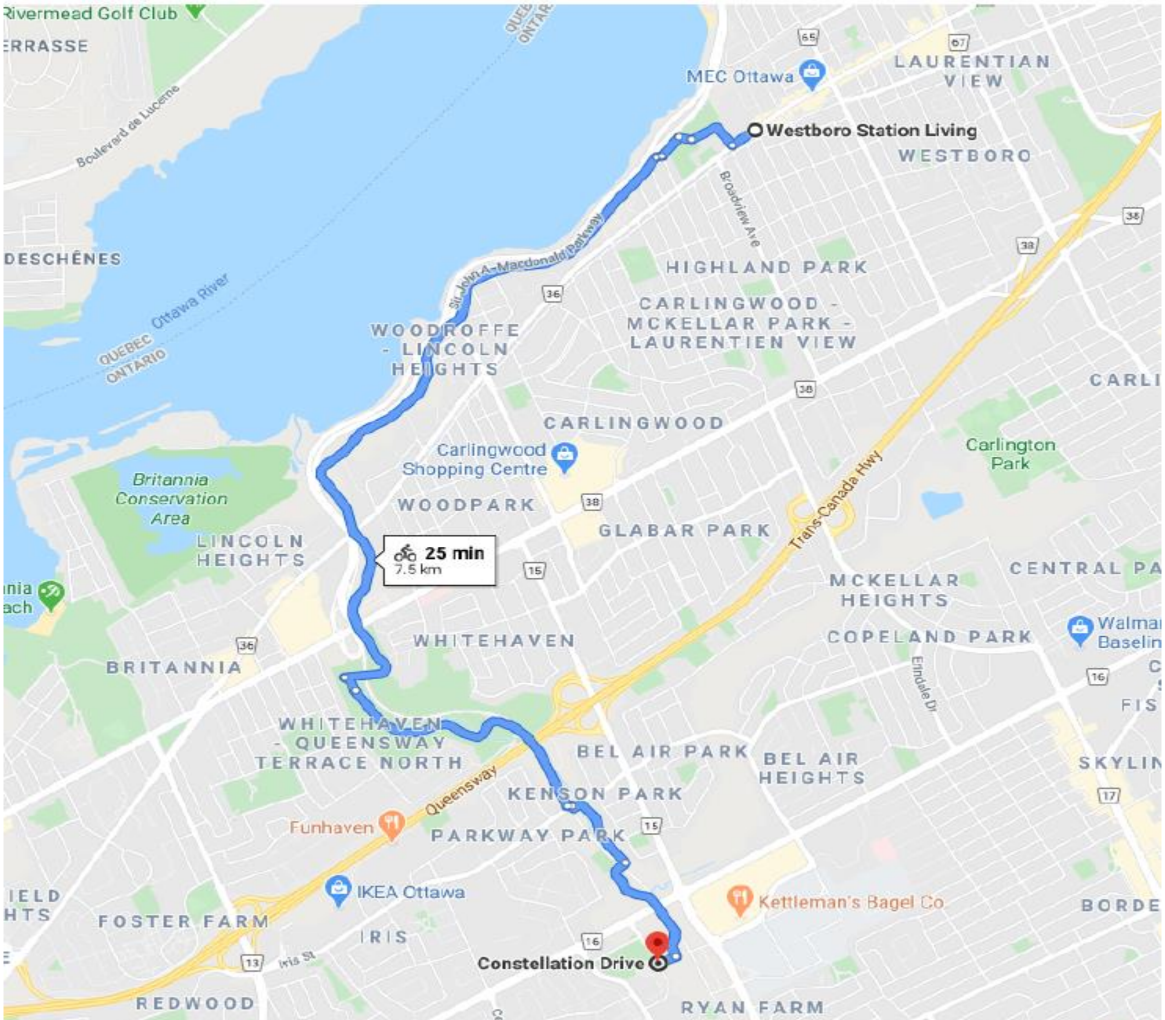

Figure 4- Sample route 3

Route 4 :444-432 RICHMOND RD TO CENTREPOINTE, NEPEAN

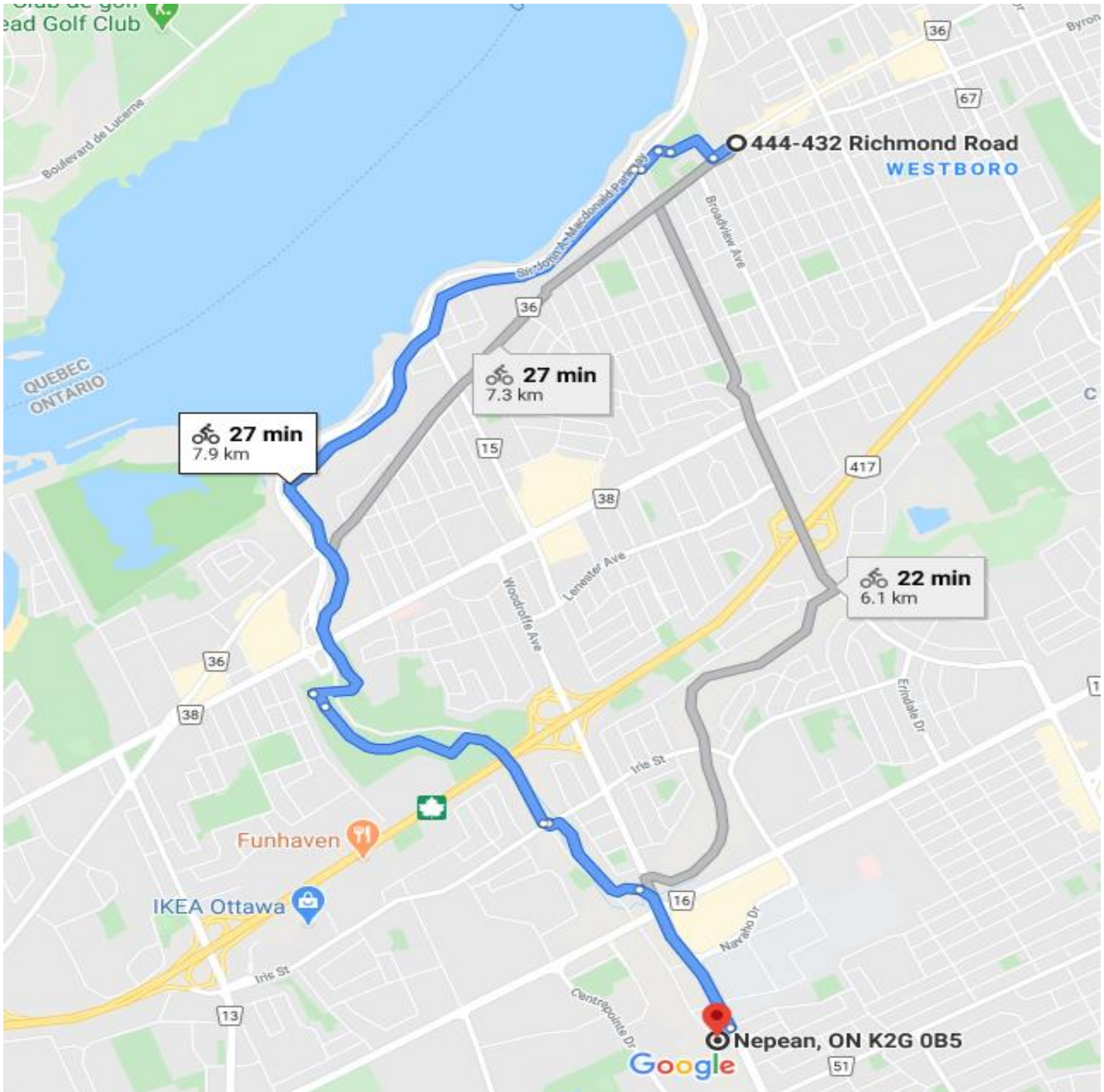

Figure 5- Sample route 4

Route 5: WOODVALE GREEN TO BELLS CORNERS UNION CEMETERY

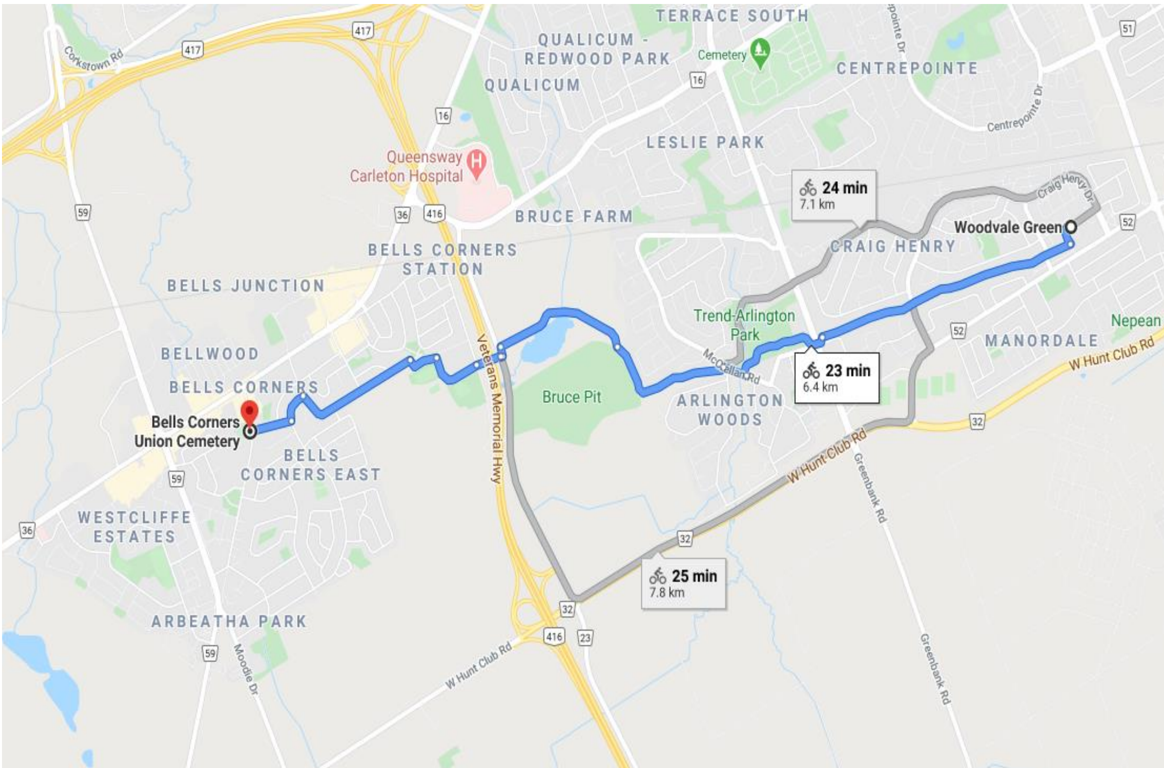

Figure 6- Sample Route 5

3.5 Workflow

Data Flow Diagrams can be used to graphically illustrate the flow of data through a system or model in GIS. More generically, Flow Diagrams (or Process Flow Diagrams) can be used to depict the movement and process steps of data, information, etc. through a system. The basic concept is a means of showing what goes in (to a system or model), what processes occur (within the system or model) and what comes out. For this project the workflow is shown as figure7.

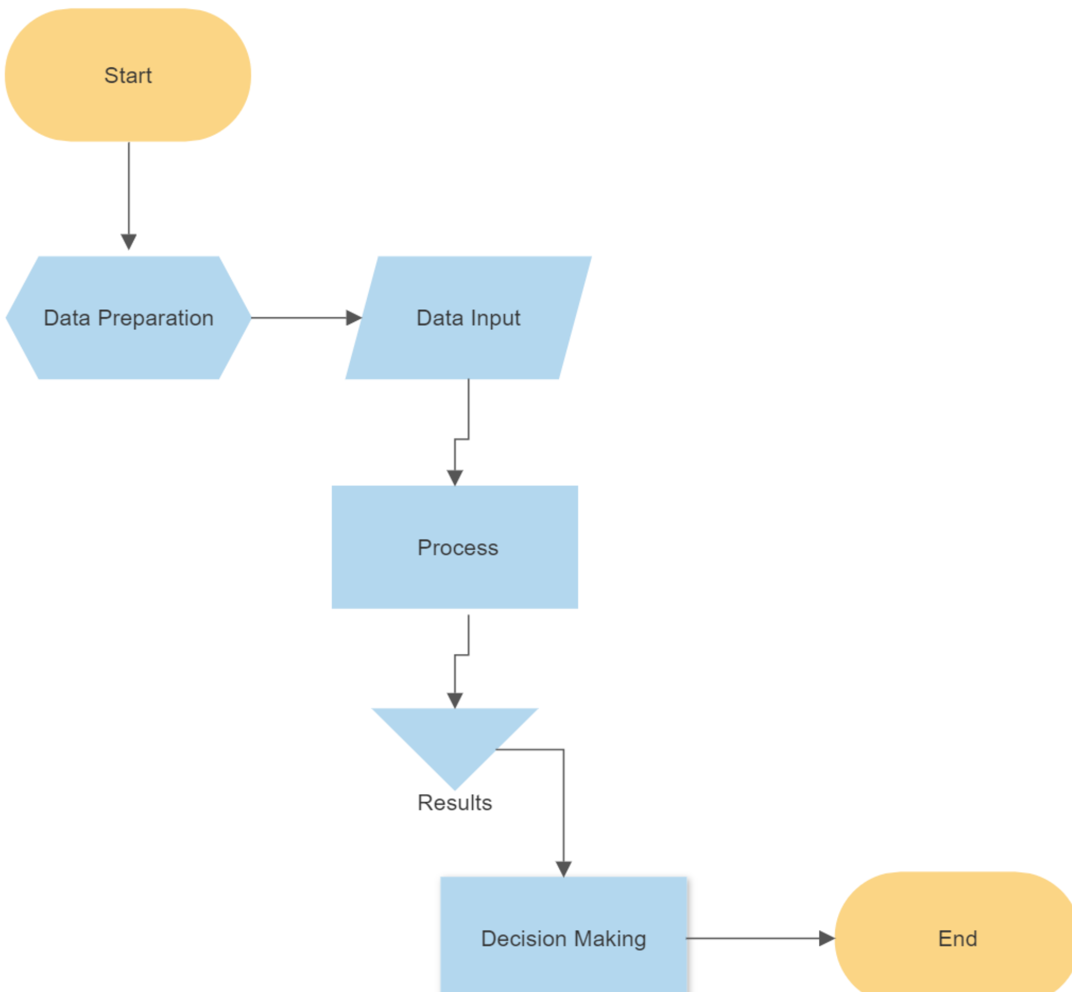

Figure 7-WorkFlow

Application of methodological approach and data sources:

- Choosing a multi use path in Ottawa region for cycling, walking and running with the length of not more than 10 Km could be a good start.
- Accumulating data for the specified characteristics based on literature review
- Transform maps if necessary and standardize them by index overlay method before integration (Data Preparation)
- Score properties, weight them and integrate them based on weighted index overlay method (Process)

3.6 Data Preparation

Preparing data means ensuring datasets can be validly analyzed together and reducing processing time as much as possible. In figure8 it is shown that data preparation is one of the very first steps in workflow.

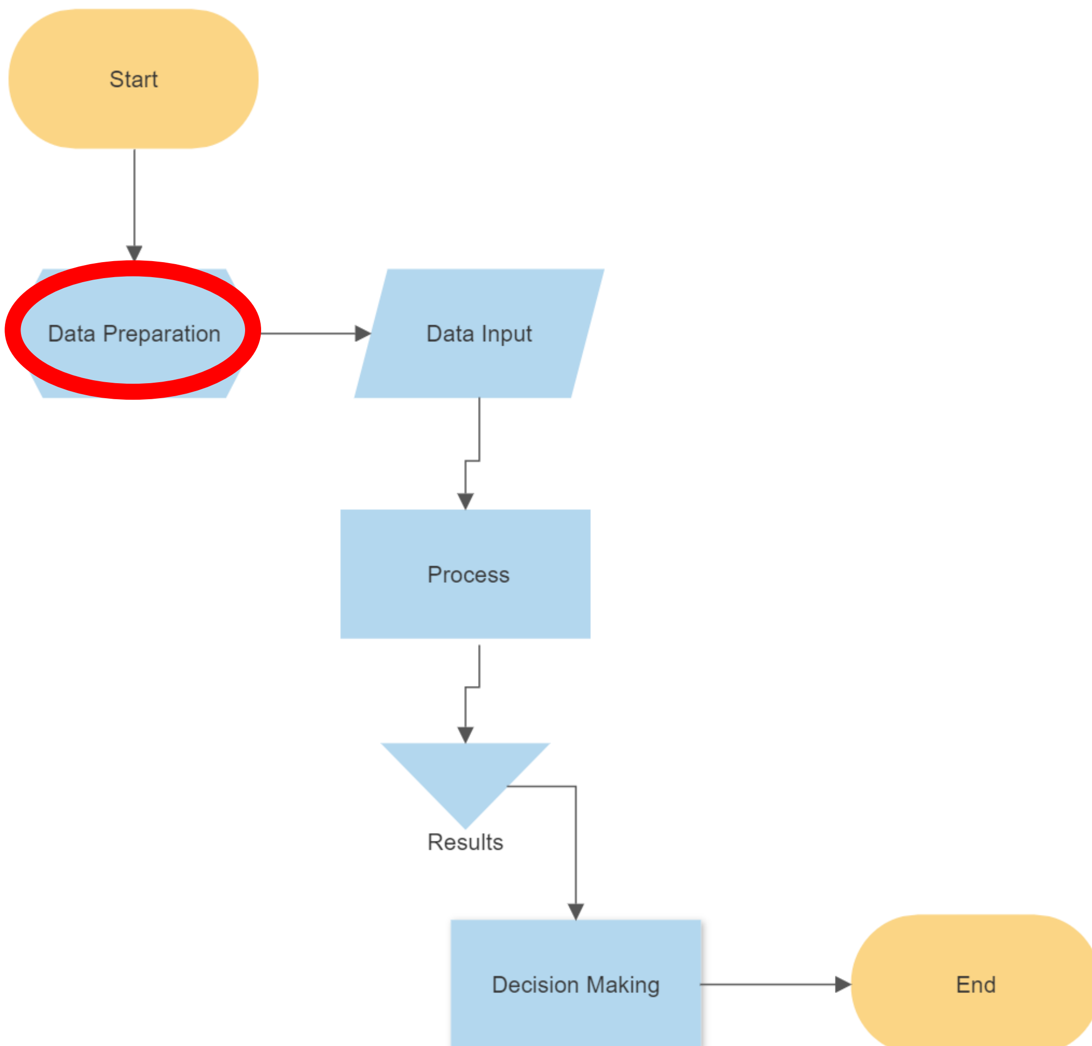

Figure 8-Workflow-Data Preparation

3.6.1 Create a geodatabase

Using the Catalog window in ArcMap Geodatabases can be created to arrange and save collected data to make a file geodatabase. The first data format to edit and data management is the geodatabase which is used as a native data structure in. ArcGIS is known for working with geographic information in different geographic information system (GIS) file formats. So, it should be able to work with and benefits the abilities of the geodatabase. Geodatabases have a complete data model for illustrating and managing geographic data. This model is applied as a string of tables including feature classes and attributes. Moreover, advanced GIS data objects add real world behavior; rules for managing spatial integrity; and tools for working with spatial relationships of the core features and attributes. Geodatabases come in various sizes. It have different numbers of users and it can scale from small, single-user databases built on files up to larger workgroup, department, and enterprise geodatabases accessed by many users.

In this project LoHS (Level of Heat Stress) geodatabase (as it is shown in figure9 and 10) was created in ArcCatalog (ArcCatalog provides a catalog window that is used to organize and manage various types of geographic information for ArcGIS for Desktop to arrange and save collected data to make a file geodatabase).

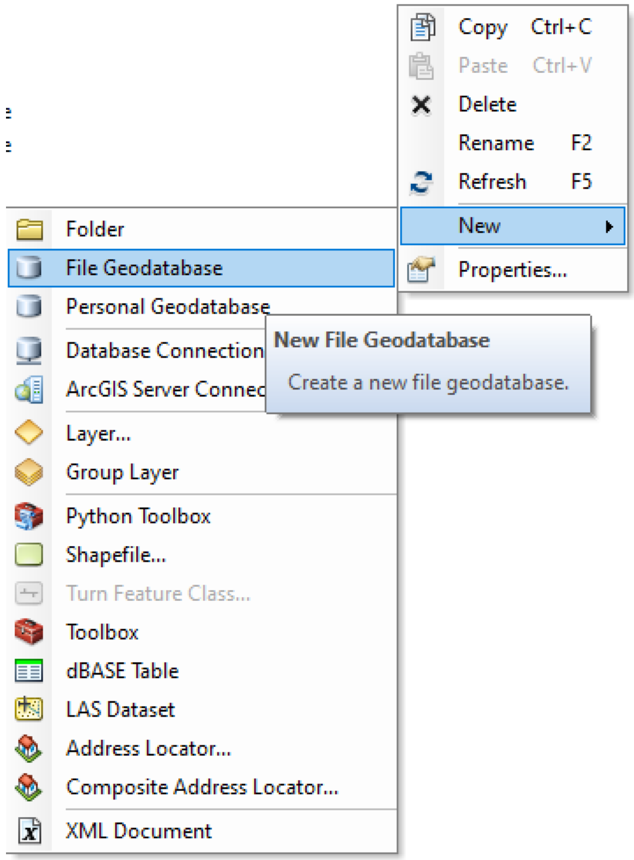

Figure 9- Creating new Geodatabase in ArcCatalog software (provided by Esri (ArcGIS) to organize data)

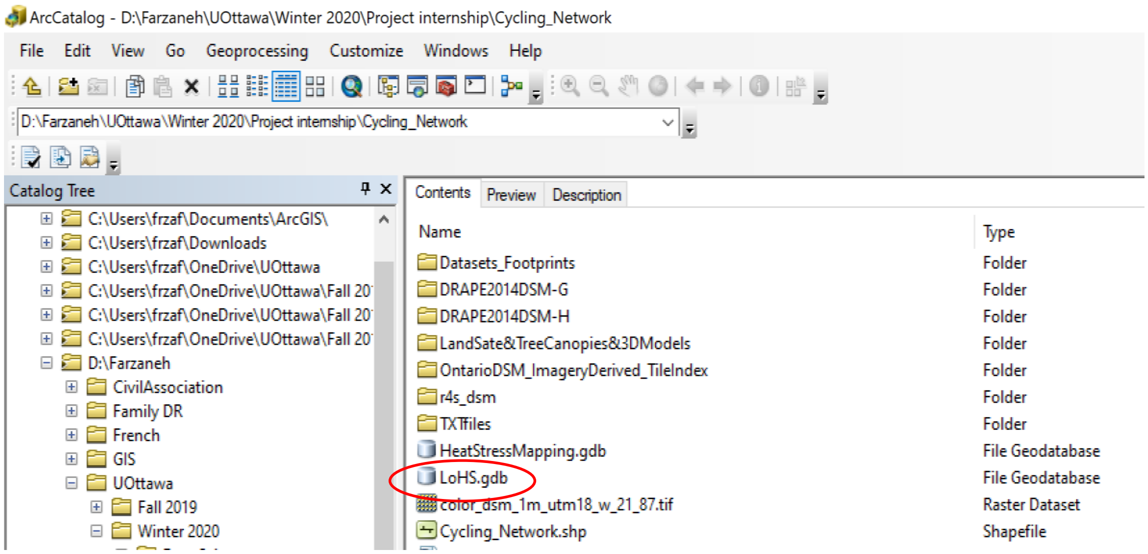

Figure 10- Created Geodatabase for the project in ArcCatalog software (provided by Esri to organize data)

3.6.2 Collecting Data

The most time consuming and hardest part of this project was collecting and preparing data. Based on the literature review 3 main data were needed to be collected for this project. The data that were collected and used for this project were:

1-Ottawa Cycling Network

2- DSM (Digital Surface Model) of Ottawa to extract slope map from it

3- Landsat images to extract temperature of the locations in the trails and considering heat island effect

4- Tree canopies around the chosen trails

3.6.2.1 Ottawa cycling network

By downloading cycling network from https://open.ottawa.ca/ (shown in figure 11) sample trails could be extracted by selecting polylines and merge them to a single line through **Create Routes (Linear Referencing)** tool in ArcGIS

There is a tool in ArcGIS called **Create Routes (Linear Referencing)** which can get existing lines as the input feature that share a common identifier and then merge them to create a single route. In this process it is needed to select multiple lines to merge them together. So, selecting polylines will be done by clicking on the Editor Toolbar button on the Standard toolbar to display the Editor toolbar and then selecting lines while pressing Shift button on the keyboard to select multiple lines. Different commands that may be needed will be in the Editor toolbar. Starting and stopping an edit session will be done from the Editor toolbar. It gives access to a vast range of tools and commands to create new features and modify existing ones and save the edits. To edit data, as it is shown in figure12 and figure13 it is needed to add the Editor toolbar to ArcMap by clicking the Editor Toolbar button on the Standard toolbar. Editing should be stopped by clicking on Stop Editing and then using Merge selected lines through Create Routes (figure14) (Linear Referencing).

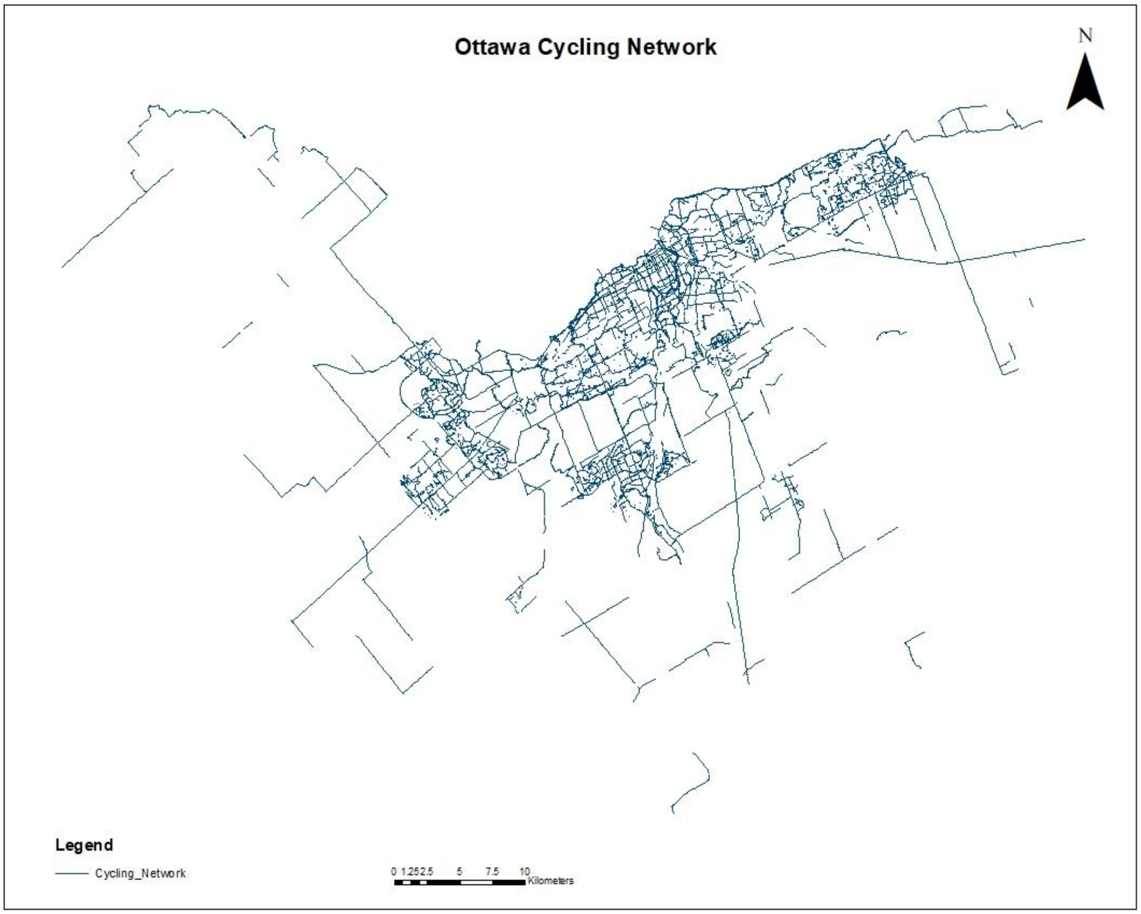

Figure 11- Ottawa Cycling Network

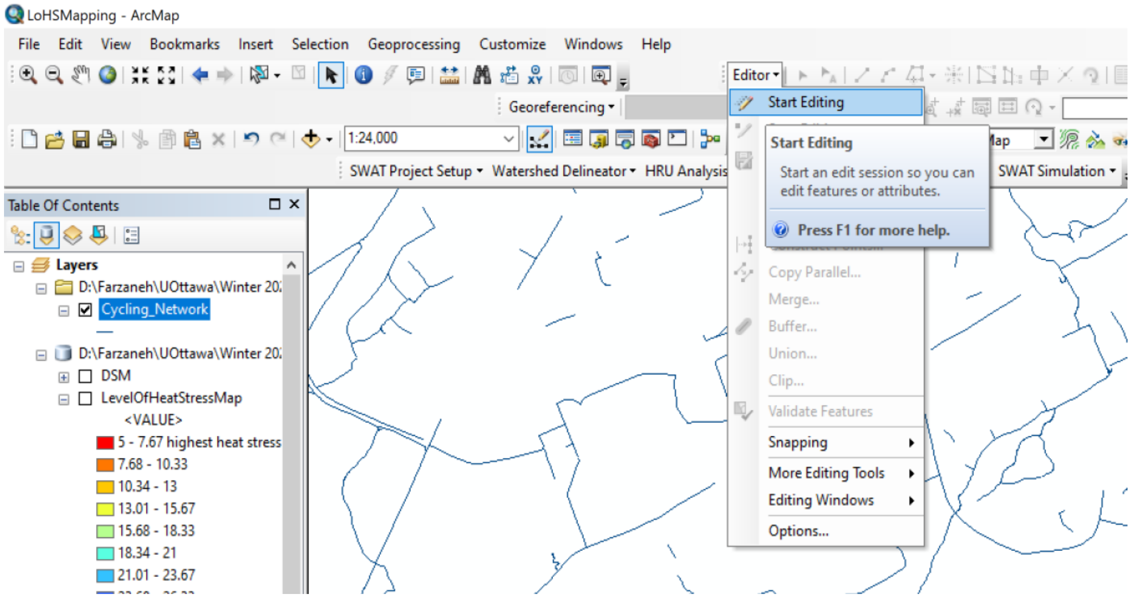

Figure 12- Selecting Routes from Ottawa Cycling Network in ArcMap

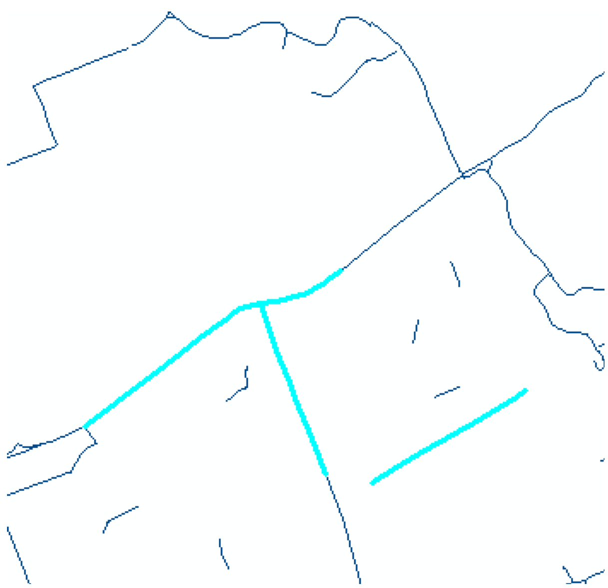

Figure 13- Selected Cycling Route in ArcMap

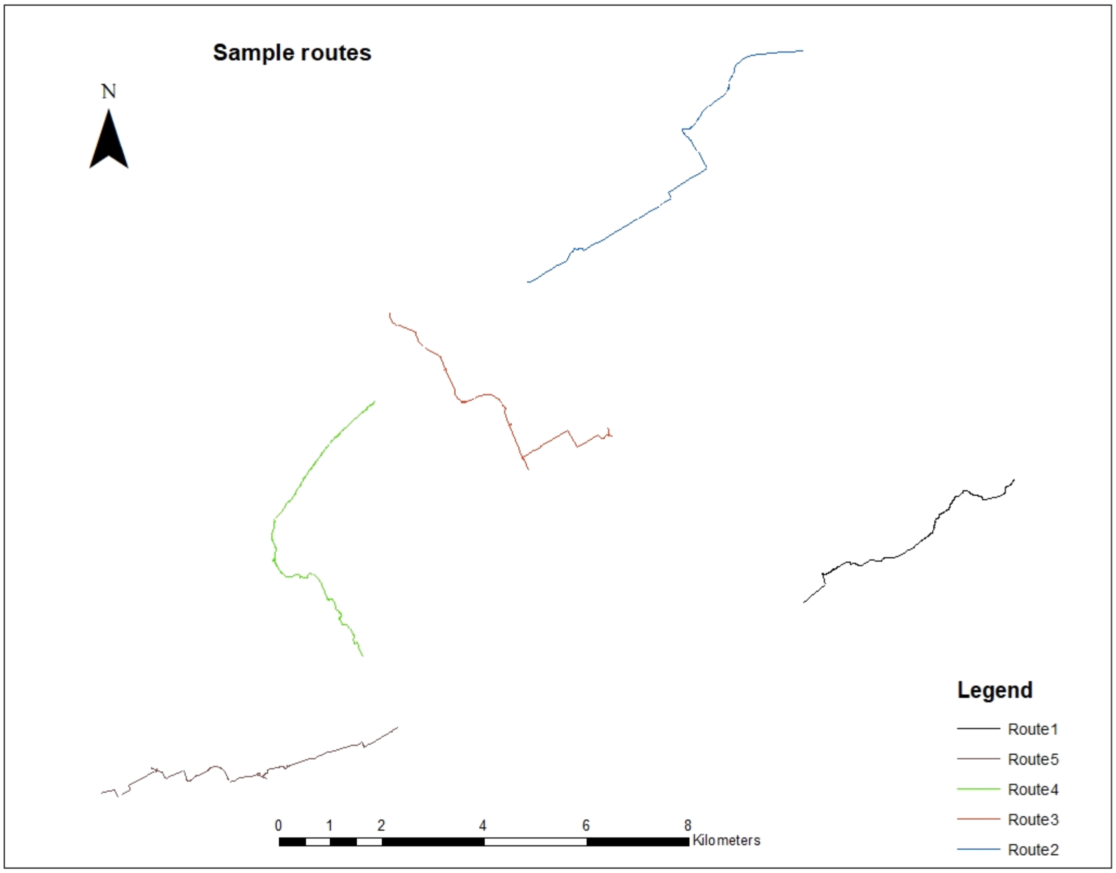

Figure 14- All Sample Route in a view

3.6.2.2 DSM

A Digital Surface Model (DSM) is an elevation model that contains the elevation of the terrain as well as above-ground features such as buildings, vegetation, towers, and other infrastructure. A digital surface model (DSM) takes the natural and man-made features on the Earth's surface. It represents the earth's surface elevation including vegetation and built structures. Pulses of light transfer to the earth surface in LiDAR system . After the pulse of light reflect from their target they go back to the sensors, a variable distance to the Earth will be calculated in this way. Consequently, this system got its name of Light Detection and Ranging. At the end, LiDAR receives lots of point cloud including varying elevation values. But these elevation can come from the top of buildings, tree canopy, powerlines and other features. DSM represent a continuous elevation values over a topographic surface, containing vegetation and built features, by a typical array of z-values, referenced to a mutual datum. To represent the terrain relief that includes the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth DSMs are typically used.

In this Project DSM files for the trails were collected from: https://geohub.lio.gov.on.ca/datasets/mnrf::ontario-digital-surface-model-imagery-derived

There was a huge amount of DSM pictures for the whole Ottawa. So, only the rasters that covers the trails which were about 80 rasters were collected for this project and they had to be mosaic to new raster then the Slope map could be extracted from DSM. Mosaic to new Raster is a tool that merges multiple raster datasets into a new raster dataset. It will be used whenever the input raster datasets are all the raster datasets and they would be liked to mosaic together. The inputs must have the same number of bands and same bit depth; otherwise, the tool will exit with an error message. Sometimes, when working with a large number of raster datasets, the Raster Catalog to Raster Dataset tool or Creating Mosaic Dataset in ArcCatalog perform efficiently. For this project Mosaic dataset was created in ArcCatalog.

First, it is needed to create mosaic data set in ArcCatalog like figure15, 16, 17.

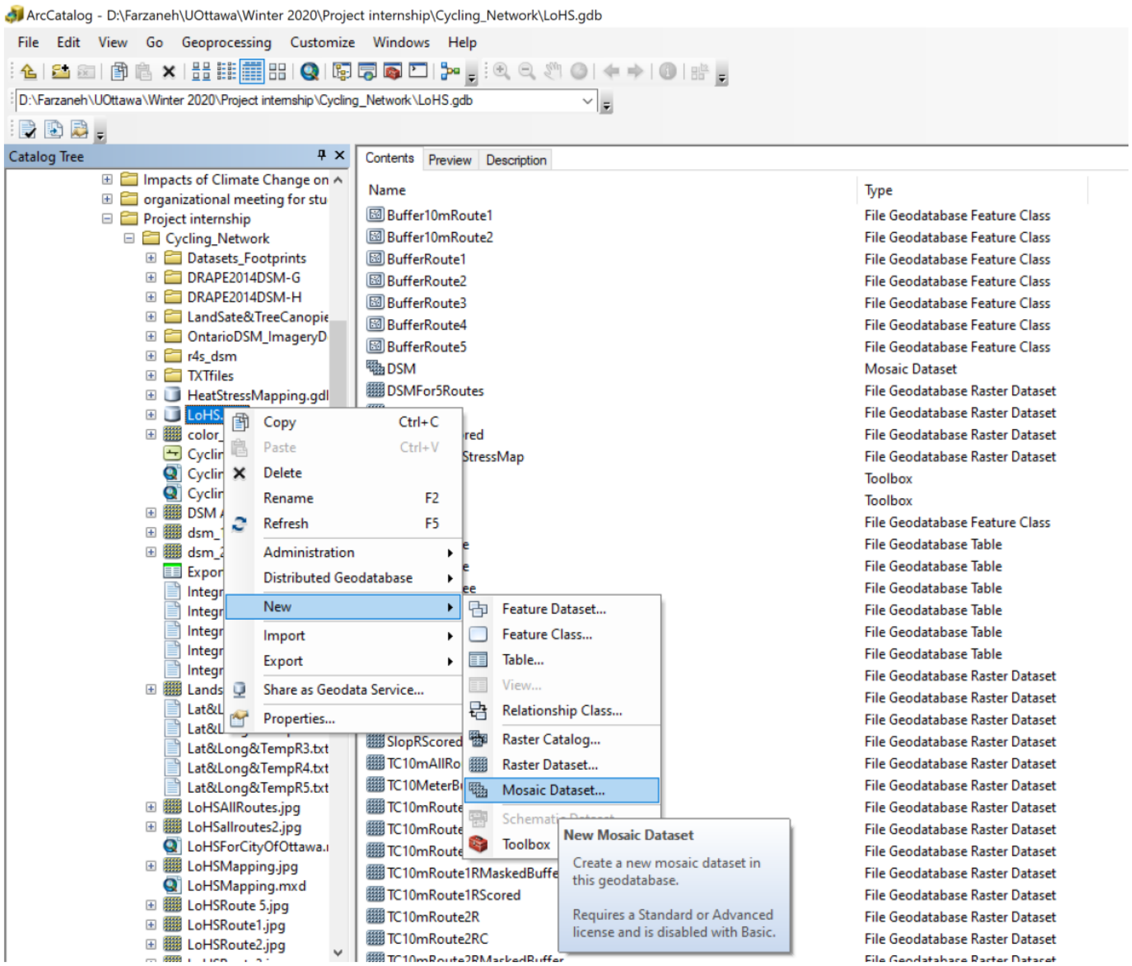

Figure 15-Create Mosaic Dataset in ArcCatalog software (provided by Esri to organize data)

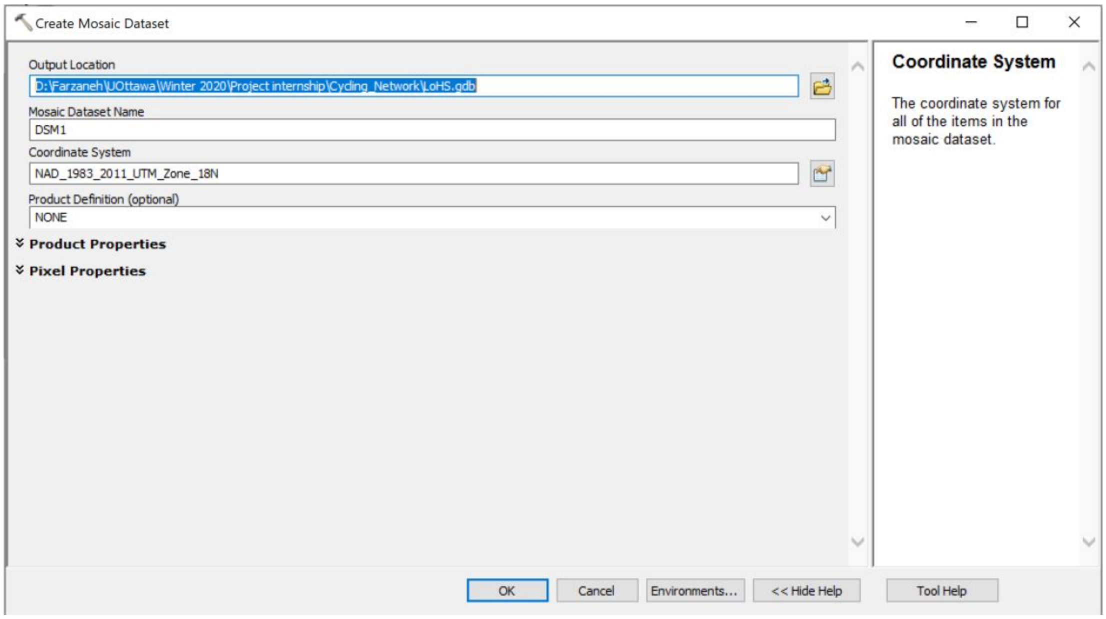

Figure 16-Mosaic Dataset in ArcCatalog

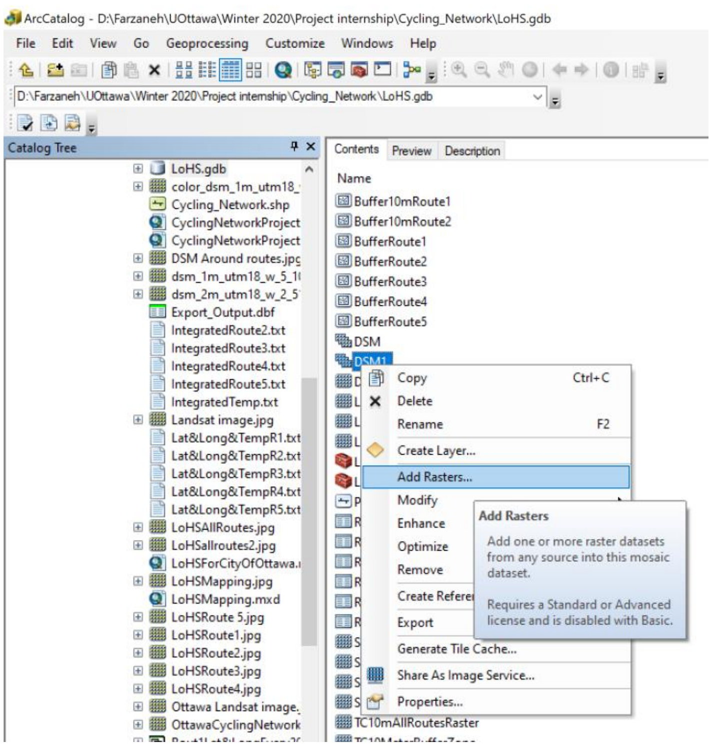

Figure 17-Adding rasters in Mosaic Dataset in ArcCatalog

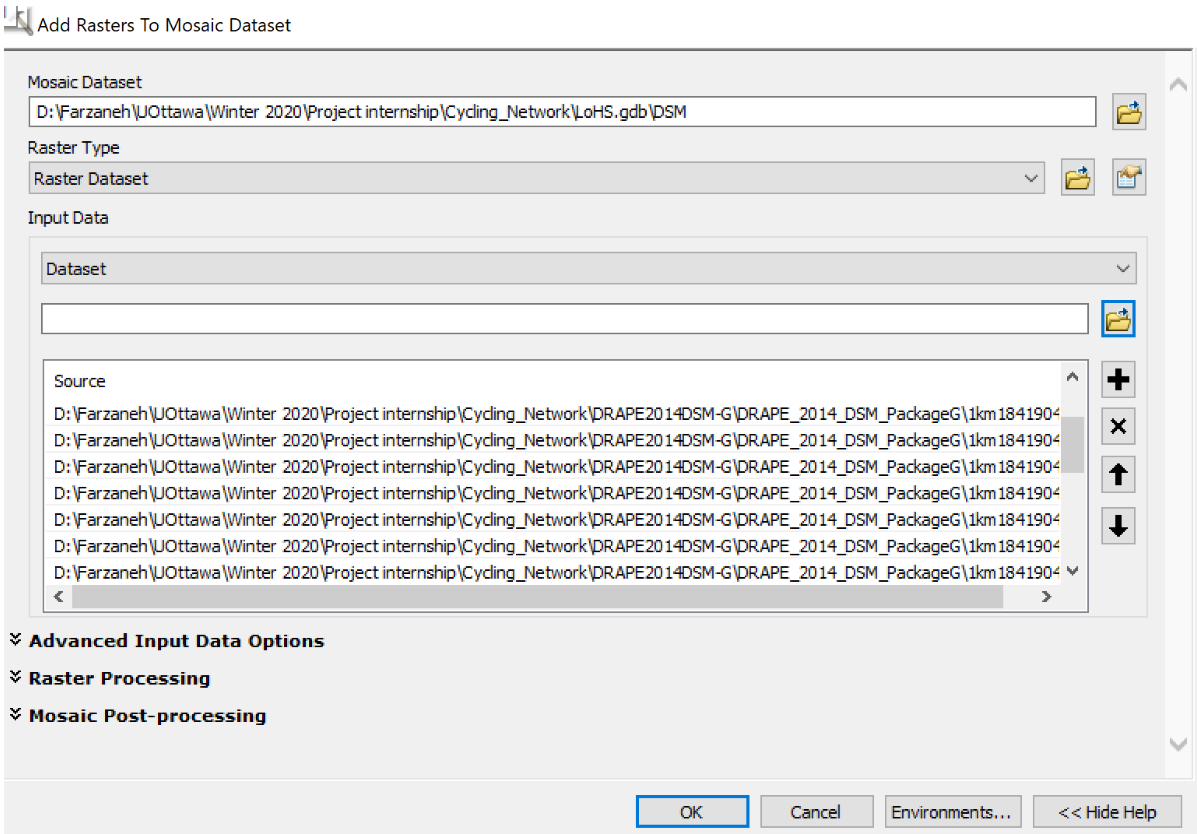

Figure 18-Add rasters to Mosaic Dataset in ArcMap

When this tool runs (Figure18) it adds the data, calculates the information it needs, and generates the overviews (Figure19 and 20). Once it is complete, the mosaic dataset will be ready to use. Then the mosaic raster will be added in ArcMap and it will be added as a custom group layer.

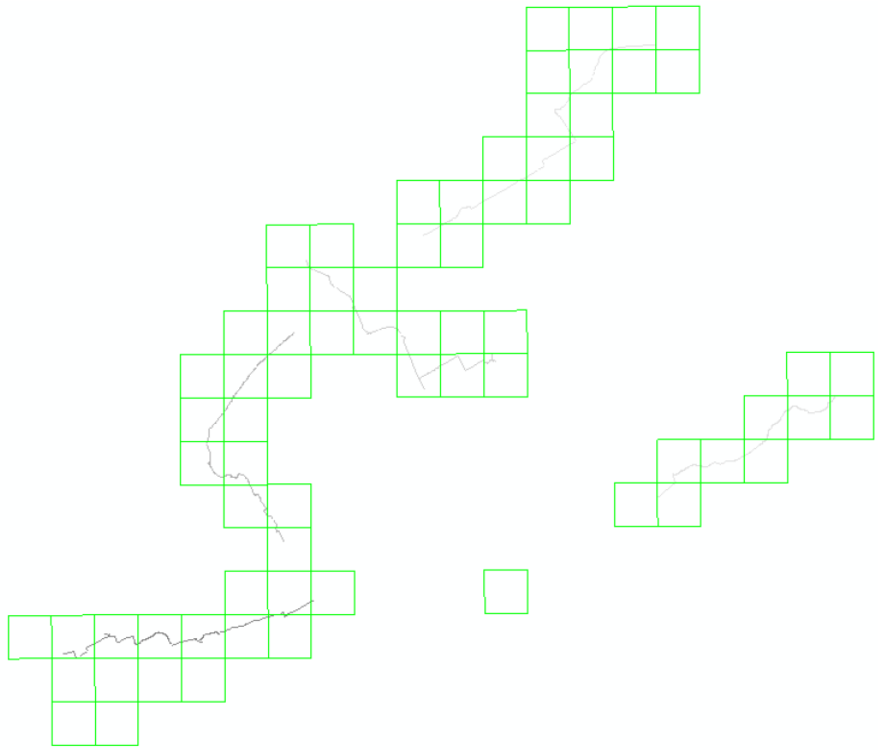

Figure 19- Selected DSM rasters for selected sample routes Shown in ArcMap

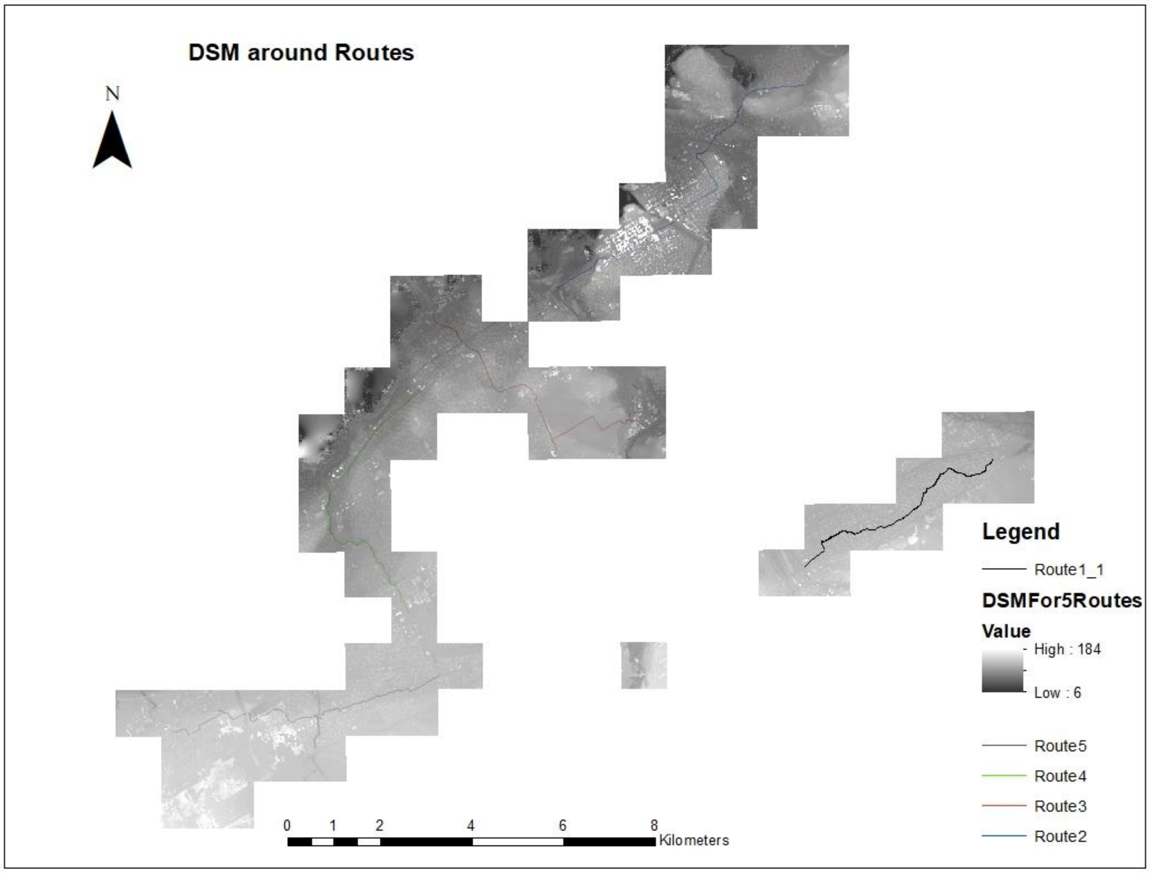

Figure 20- Applied DSM on all sample routes in ArcMap

3.6.2.3 Extract Slope from DSM

Digital Surface Model (DSM) in GIS was used to generate slope values as attributes for road segments across the city (Figure21 and 22). Slope map was created using Slope (Spatial Analyst) tool and DSM as an input raster based on degree. The Slope (Spatial Analyst) tool identifies the slope (gradient or steepness) from each cell of a raster. Illustrate that this tool uses a 3 by 3 cell moving window to process the data. If the processing cell is NoData, the output for that location will be NoData. Of the eight cells neighboring the processing cell, this tool requires that at least seven of them have a valid value. If there are fewer than seven valid cells, the calculation will not be performed, and the output at that processing cell will be NoData. The cells in the outermost rows and columns of the output raster will be NoData. This is because along the boundary of the input dataset, those cells do not have enough valid neighbors. The range of values in the output depends on the type of measurement units. For degrees, the range of slope values is 0 to 90 and for percent rise, the range is 0 to essentially infinity. A flat surface is 0 percent, a 45-degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger. For this project the out put were selected as degree and then slope values were considered into four categories for being merged later on in Process step: 1) 0.0 to 3.0%, 2) 3.1 to 5.0%, 3) 5 to 10%, 4)10 to 15% and 5)greater than 8.0%.

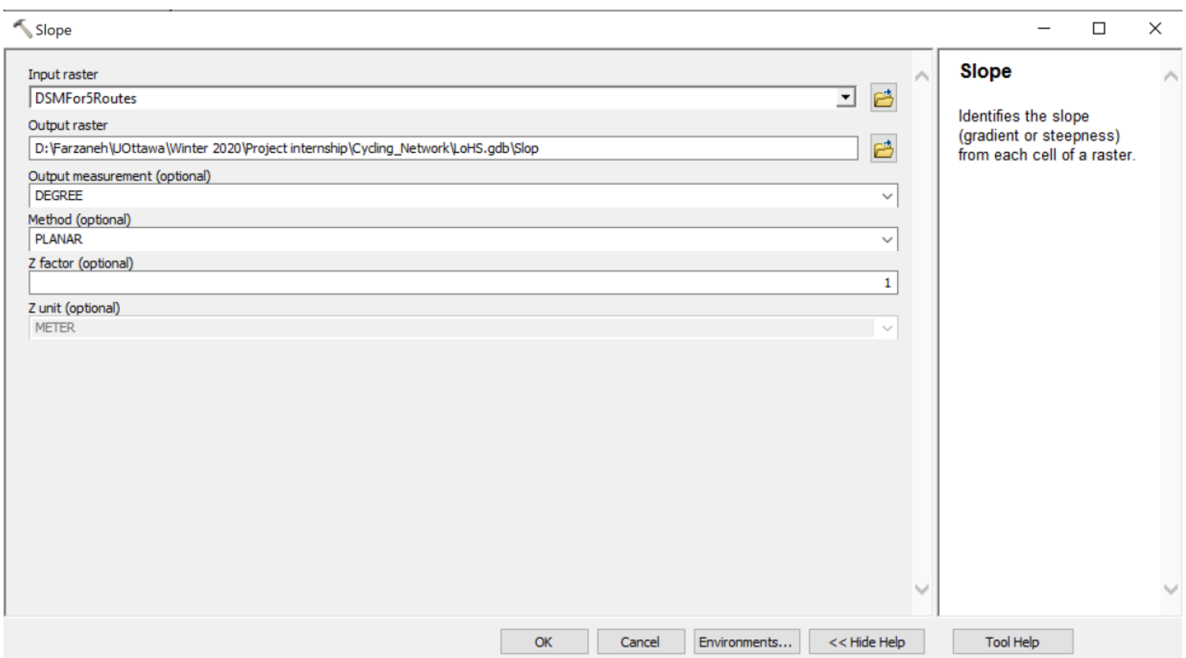

Figure 21- Extracting Slope from DSM in ArcMap

Figure 22- Calculated Slope Map In ArcMap

3.6.2.4 Landsat Images of Ottawa

Landsat 8 is an earth observation satellite, which watch the earth in a specific way. It takes images around the globe to disclose the earth's events, including volcano’s activity to urban sprawl. These images provide an increasingly powerful tool for mapping and visualizing the world. Not any other platform comprises as much area in as tiny time like 16 days. Landsat works with electromagnetic spectrum, including what is not visible to the human eye. Scientists and GIS analysts use Landsat to keep an eye on places and the changes of the earth including the temperature. Thermal bands from Landsat 8 can be used to calculate temperature. For this project the landsat8 images related to 2019 was collected from City of Ottawa GIS department (Figure 23). This data was used to find the average temperature along the sample trails and considering the Heat Island Effect.

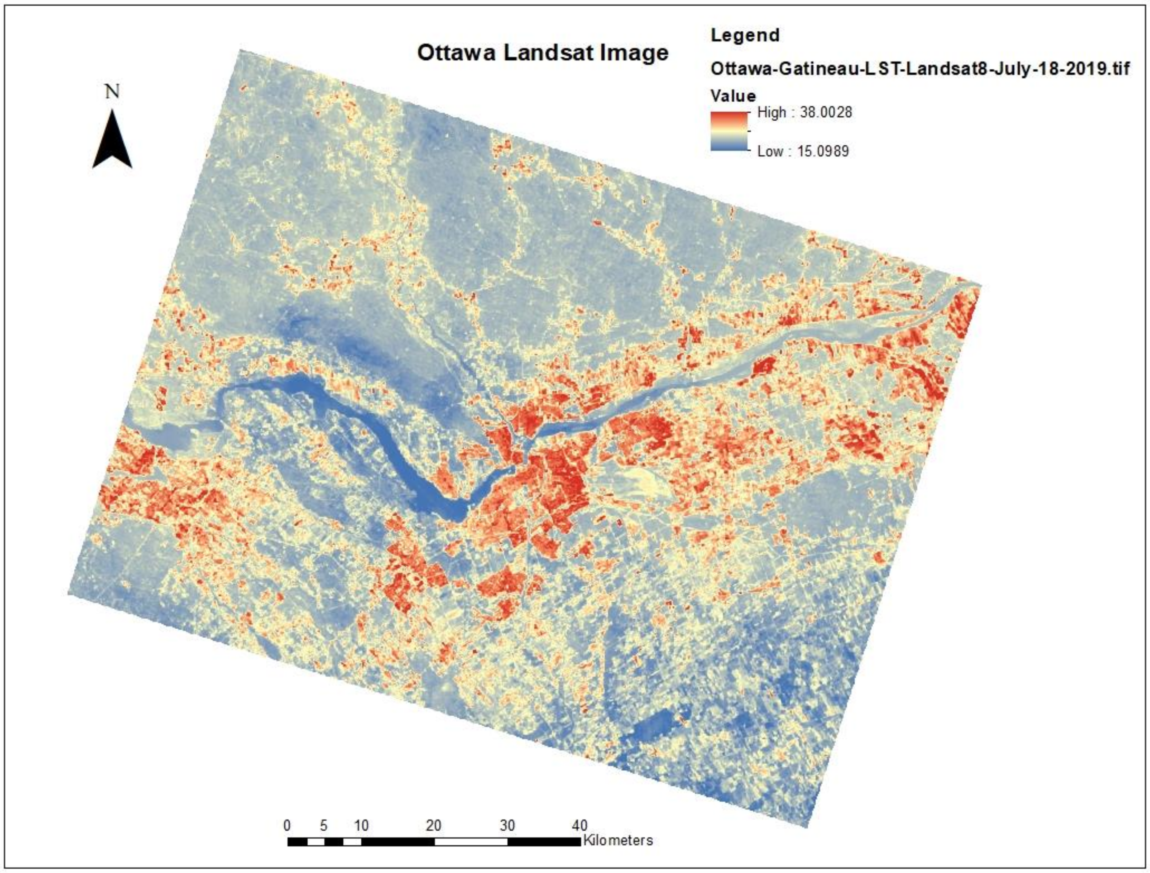

Figure 23- Ottawa Landsat Image

3.6.2.5 Tree Canopies

Figure 24- Ottawa Tree Canopy retrieved from http://maps.ottawa.ca/geoOttawa/

The tree canopy shape file within 100 meter distance to the trails was given by city of Ottawa GIS department (figure27). The tree canopy map measured the tree canopy, the layer of tree leaves, branches and stems that provide tree coverage of the ground when viewed from above which provide shaded areas that covers the trails and make the trails cooler. Therefore, Shaded harmonized streets and public paths are expected to lower outdoor heat stress (Middel et al., 2016). Cooler, more attractive, better designed and pedestrian friendly pathways, will be accessible with shaded areas which plays an essential role in this issue (Middel et al., 2016). Also, Urban Green Space Cooling Effect is described exactly for this reason. The impact that urban green areas have on vicinity areas and its effect to decrease the Heat Island Effect (HIE) is one of the most important things that was considered in this study. So, planting trees, vegetation, and lawns in different amount, size and level like parks, forests and green areas will help within this purpose. It has been already revealed that "green infrastructure" will decrease the HIE (Sodoudi et al., 2014). To fulfill this purpose the tree canopy shape file within 100-meter distance to the trails was collected from city of Ottawa GIS department. To input this data to our calculations we should change it to raster file to make all the input data in the same format and also we should consider that the trees with the distance not more than 10 meter to the trails otherwise it does not really make any shades on the trail so we should limit the tree canopy file to 10 meter instead of 100 meter. To do so, we used Select by Location tool (Figure25). With this tool features in a layer are selected based on a spatial relationship to features in another layer. Each feature in the Input Feature Layer is evaluated against the features in the Selecting Features layer or feature class; if the specified Relationship is met, the input feature is selected. This tool works on layers in ArcMap, ArcGlobe, or ArcScene and also on layers created in models and scripts using the Make Feature Layer tool. The centers of the selected polygons (Tree Canopy polygons with 10 meter distance from the trails) are inside the 10 meter buffer zone of the trails and then it was saved them as a new polygon file

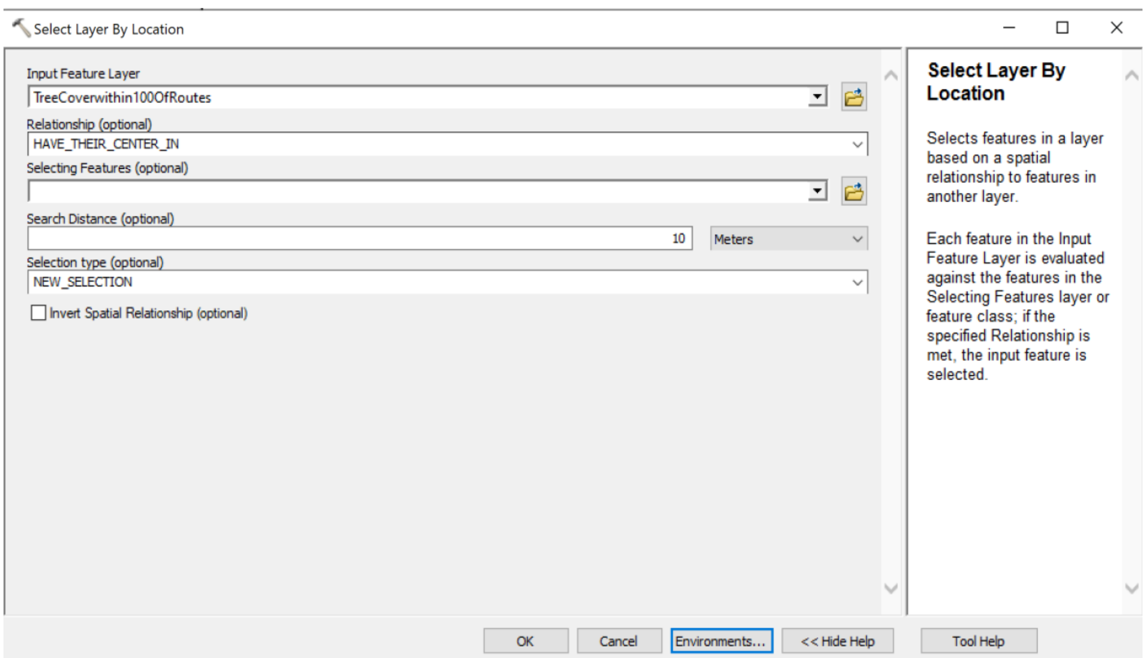

Figure 25- Selecting nearest trees to the trails in ArcMap

The next step is to transfer the output from vector to raster. To do this, there is a tool in ArcGIS called Feature To Raster. This tool Converts features to a raster dataset. By this tool any feature class (geodatabase, shapefile, or coverage) containing point, line, or polygon features can be converted to a raster dataset. The input field type determines the type of output raster. If the field is integer, the output raster will be integer; if it is floating point, the output will be floating point. The Output cell size can be defined by a numeric value or obtained from an existing raster dataset. If the cell size hasn't been explicitly specified as the parameter value, it is derived from the environment Cell Size, if it has been specified. If the parameter cell size or the environment cell size have not been specified, but the environment Snap Raster has been set, then the cell size of the snap raster is used. If nothing is specified, then the cell size is calculated from the shorter of the width or height of the extent divided by 250, where the extent is in the Output Coordinate System specified in the environment. If the cell size is specified using a numeric value, the tool will use it directly for the output raster. If the cell size is specified using a raster dataset, the parameter will show the path of the raster dataset instead of the cell size value. The cell size of that raster dataset will be used directly in the analysis, provided the spatial reference of the dataset is the same as the output spatial reference. If the spatial reference of the dataset is different, it will be projected based on the selected Cell Size Projection Method. This tool always uses the cell center to decide the value of a raster pixel. If more control is needed over how different types of input feature geometries are to be converted, refer to the respective specific conversion tools: Point to Raster, Polyline to Raster, and Polygon to Raster. When selecting the input feature data, the default field will be the first valid field available. If no other valid fields exist, the ObjectID field (for example, OID or FID) will be the default (Figure26). We do these steps 5 times for each 5 routes. The result for sample route 1 is shown in figure28.

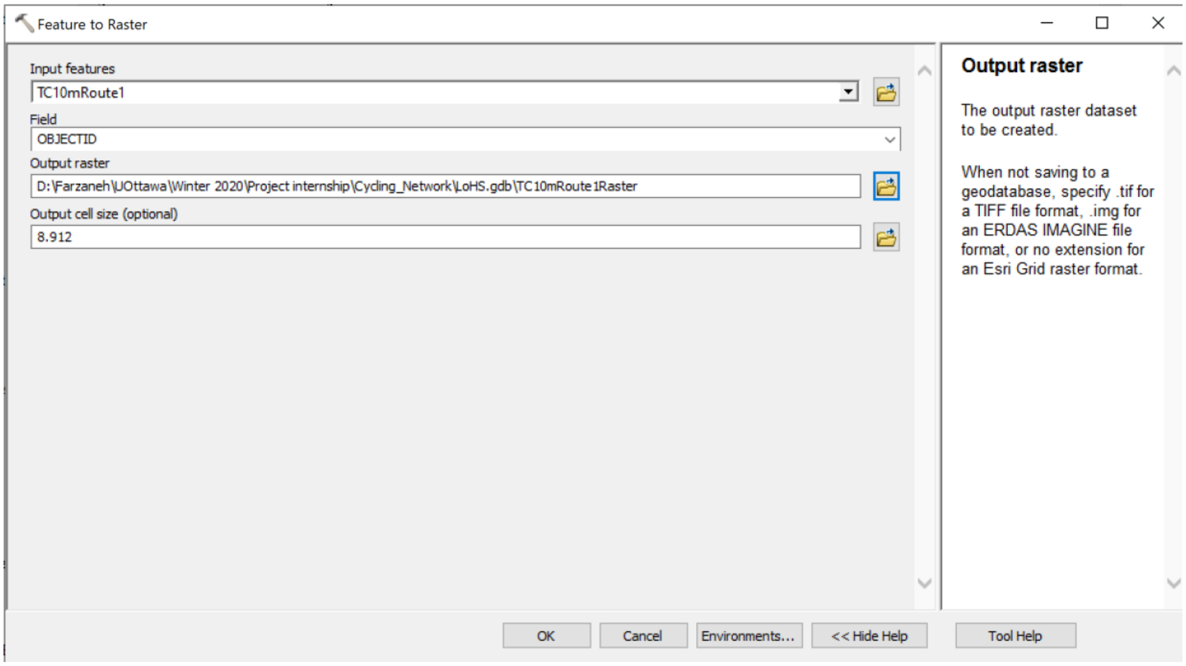

Figure 26- Make the tree canopy to the raster in ArcMap

One of the steps in processing data will be Mosaic all these Tree Canopy rasters that were created in this step. This integration of rasters could be done in this step under Data preparation or it could be done under data processing step.

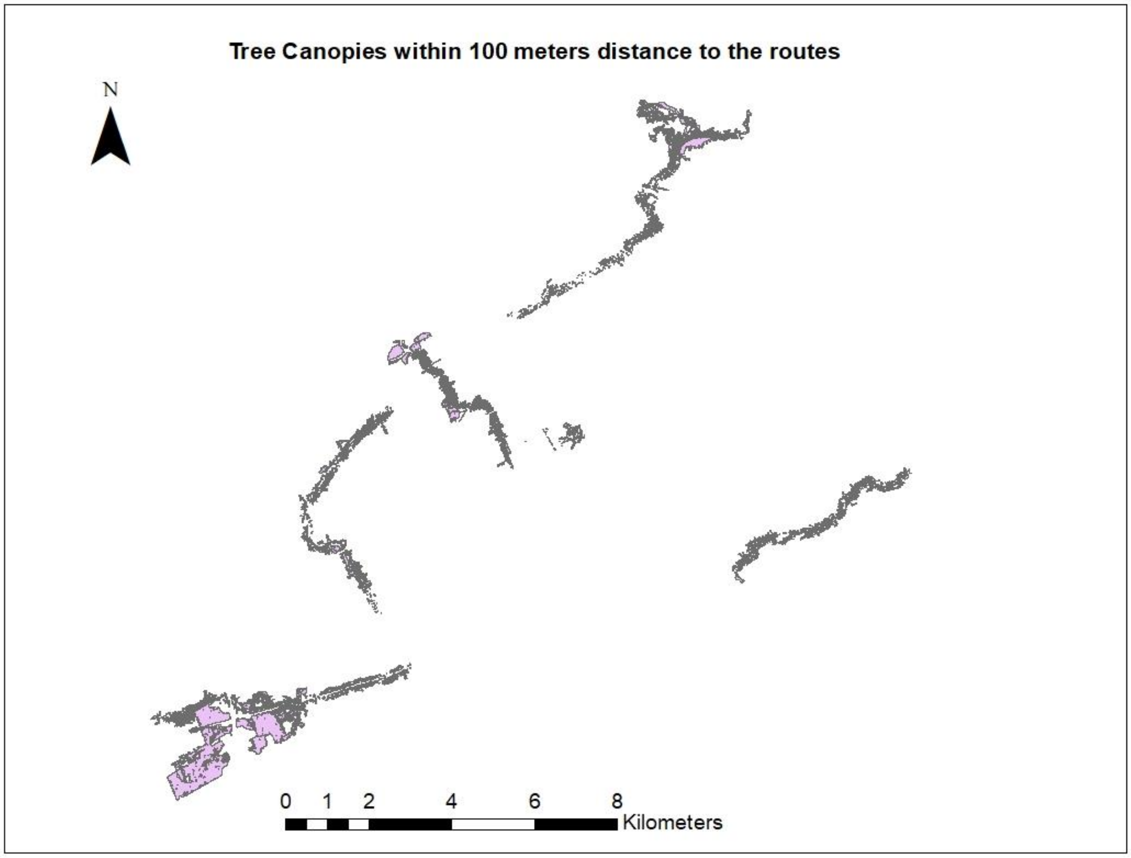

Figure 27- Tree canopy with 100 meter distance to the routes

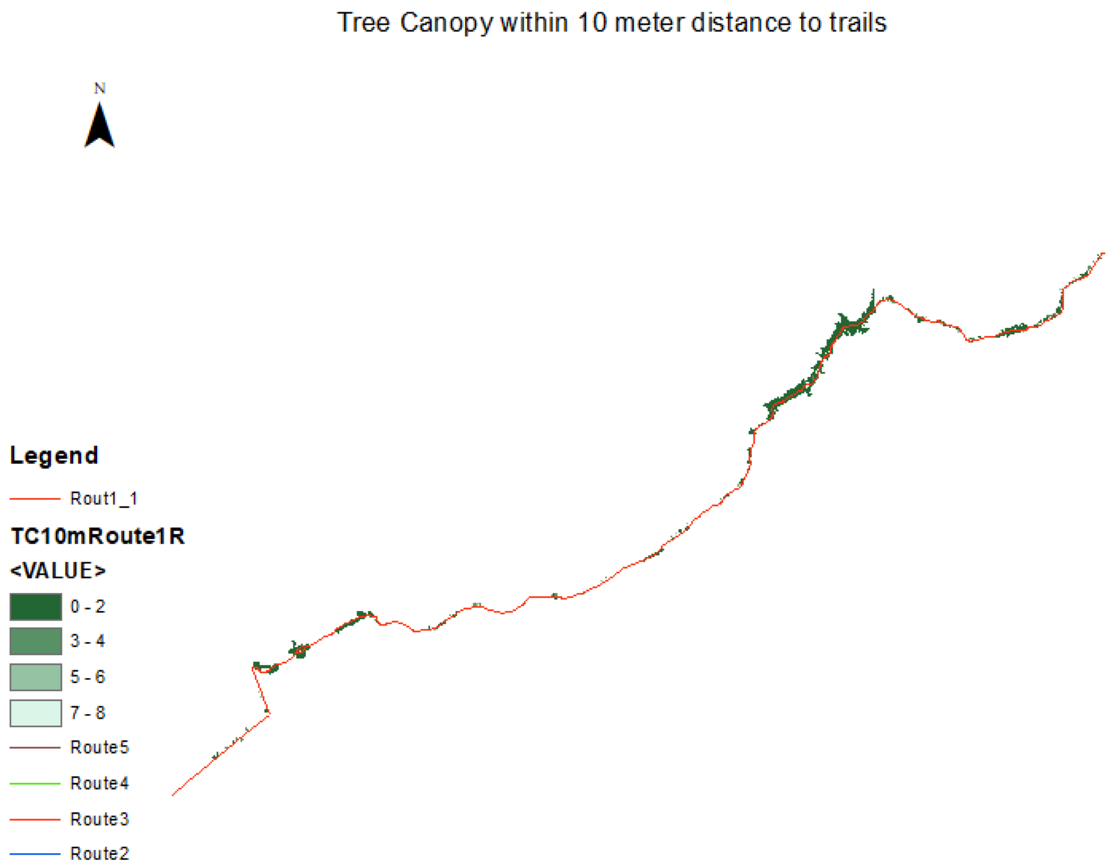

Figure 28- Tree canopy with 10 meter distance to the first sample route

3.7 Data input

All maps require input on which to apply the tools and operators to be produced. Data input in our research project is the second step in the workflow as it is shown in figure 29.

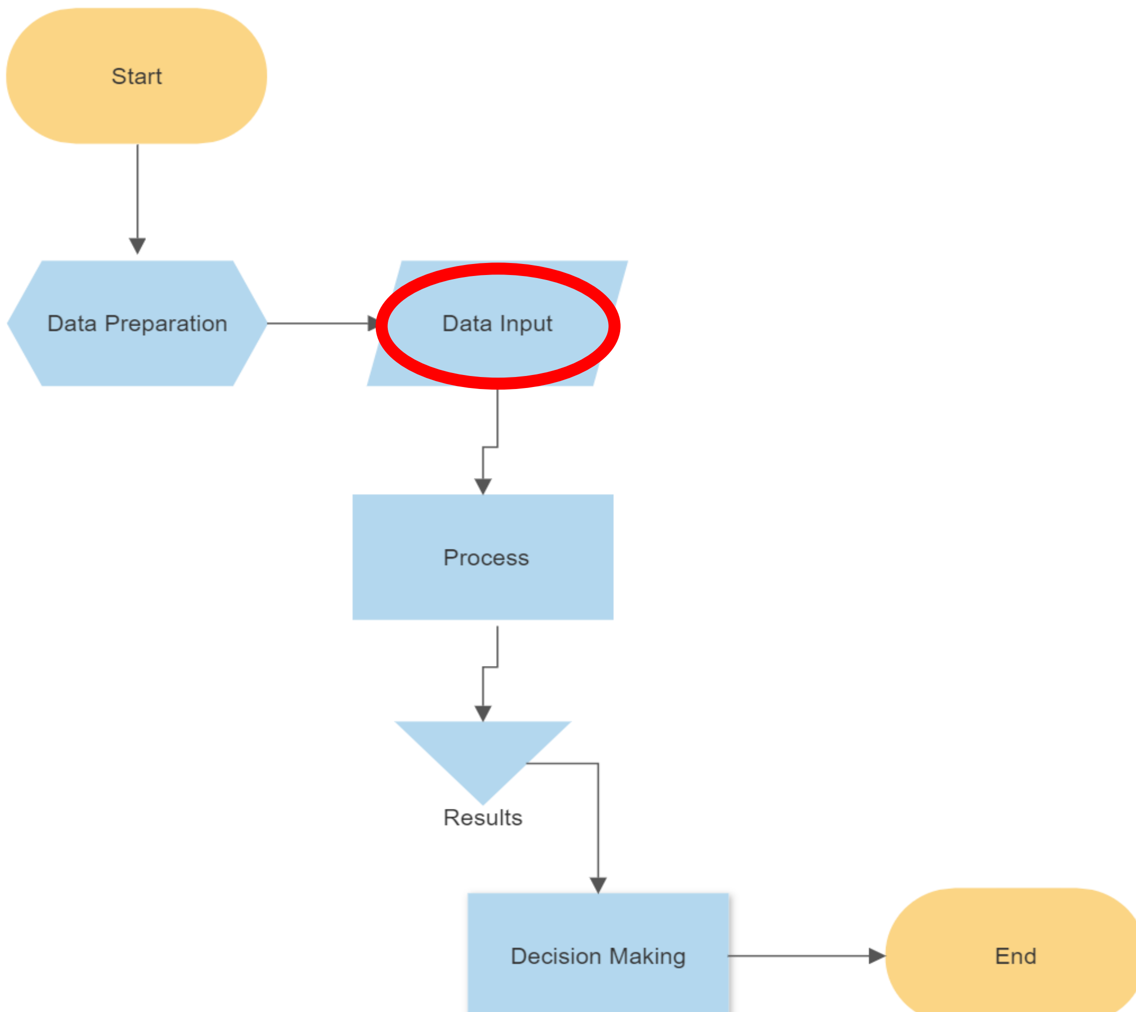

Figure 29- WorkFlow-Data input

3.7.1 Model Builder

All maps and data are required to be input for applying tools and operators on them. Model Builder was used as a visual programming language for building geoprocessing workflows to this project. The created geoprocessing model computes, runs and documents the spatial analysis and processes. The model in this study is provided as a flowchart that bonds series of processes and geoprocessing tools to each other. Models are workflows that chain sequences of geoprocessing tools together, feeding the output of one tool into another tool as input in other word using the output of one process as the input to another process.

Model Builder was used in this project because it builds a model by adding geoprocessing tools, map layers, datasets, and other data types, and connecting them to a process. Moreover, it illustrates an easy to understand workflow. Also, the model can be run step by step or for the whole model at once or on a selected step. No to mention that the model can be shared as a geoprocessing tool with others. GIS data are manageable with Model Builder. That means it can be used to create, edit, and manage geoprocessing models.

We create a model in Model Builder to add or remove tools and data to the model, and then make connections between them to establish the sequence of running.

3.7.1.1 Add geoprocessing tools

Geoprocessing tools are basic components of the model. ArcGIS toolbox has many geoprocessing tools to manage and fulfill various GIS tasks. Once the right tools for the work you are doing is defined, it is easy to add those tools to the model. When the tool is added to the model it will be typically showed as a white rectangle (figure30), illustrating that the tool is not ready to run yet and when the tools is double clicked in the model there will be a window asking for the input and output location and other information. Then the color of the tool will be changed without any shadows under the elements of the tool (figure31). The shadows will show that the tool has run or not (figure32 and 33). Any derived data features that will be created by the tool that are being located in the model are displayed in the model diagram addition to the tool itself.

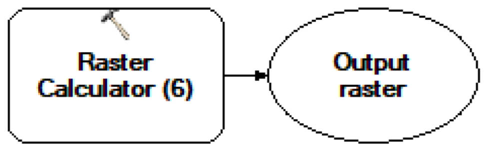

Figure 30- Tool is not ready yet to be used in Model builder Arc toolbox in ArcGIS

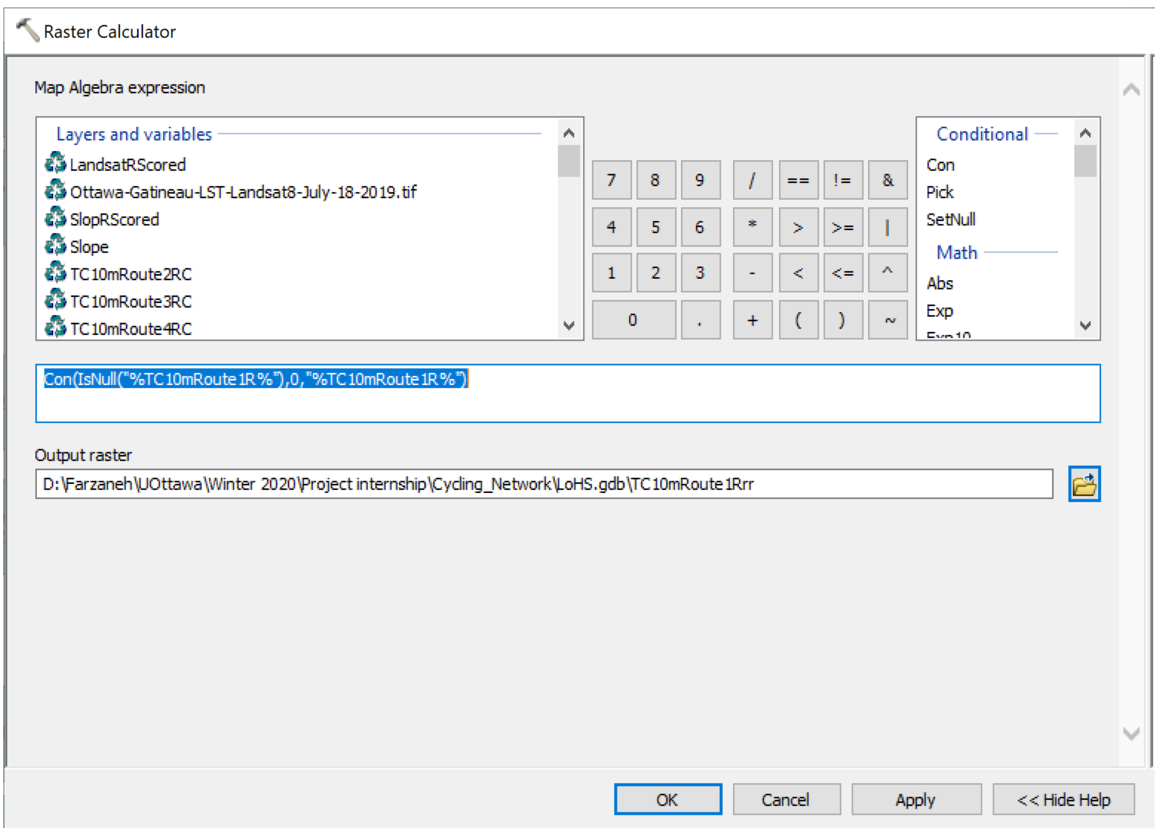

Figure 31- Raster Calculator tool in ArcMap

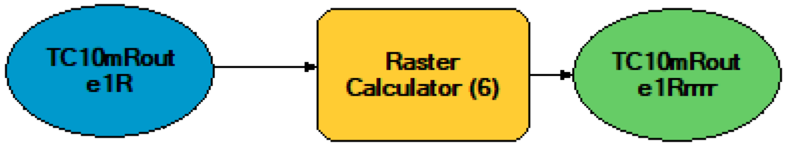

Figure 32- Raster Calculator is ready to run in Model builder Arc toolbox in ArcGIS

Shadows show that the model has run or not.

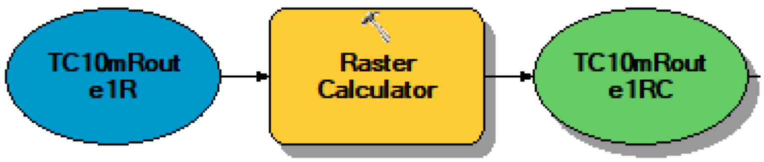

Figure 33- Raster Calculator was ran Model builder Arc toolbox in ArcGIS

3.7.1.2 Connect data and tools

Geoprocessing models are all about connecting data and tools into processes. You must specify which data variables in the model should be processed by which geoprocessing tools. Connect the data variables you added to the model directly to a tool by drawing a connection between them, then choose the tool parameter to connect the variable to. The output of one tool can be connected as input to another tool (figure34).

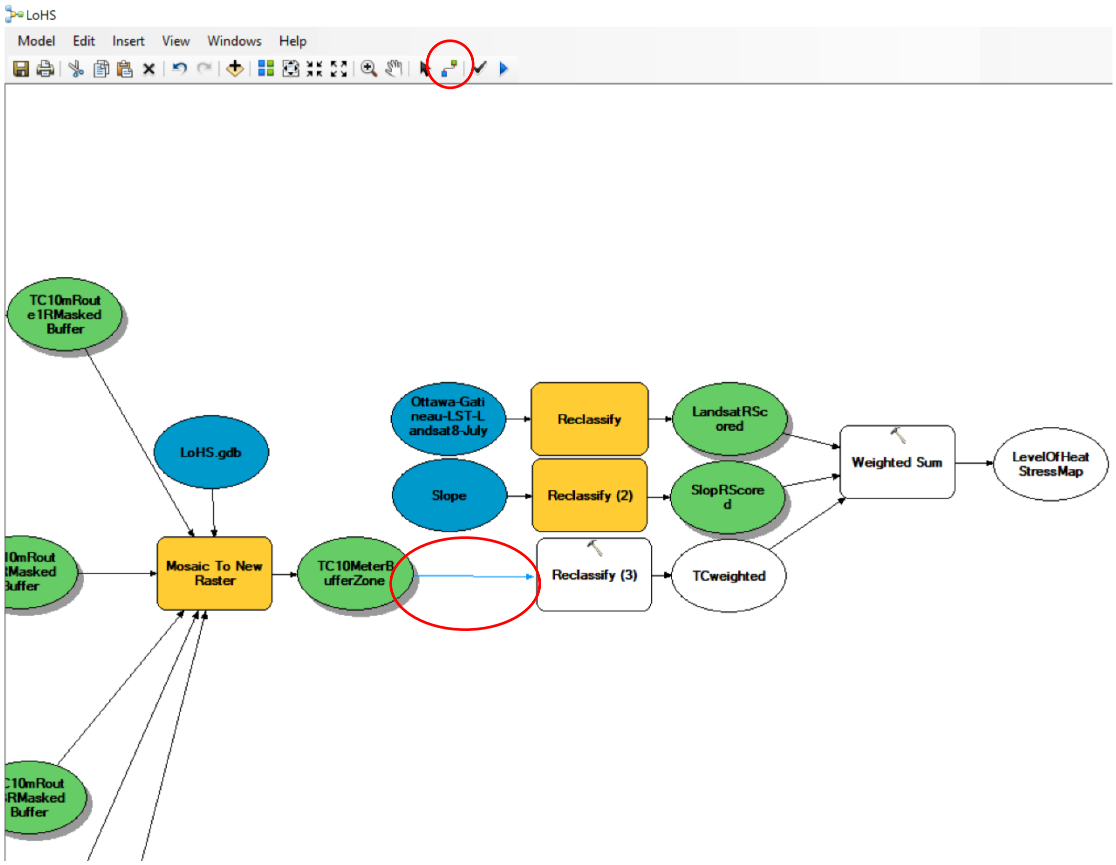

Figure 34- Connecting tools in the Model created in Model builder Arc toolbox in ArcGIS

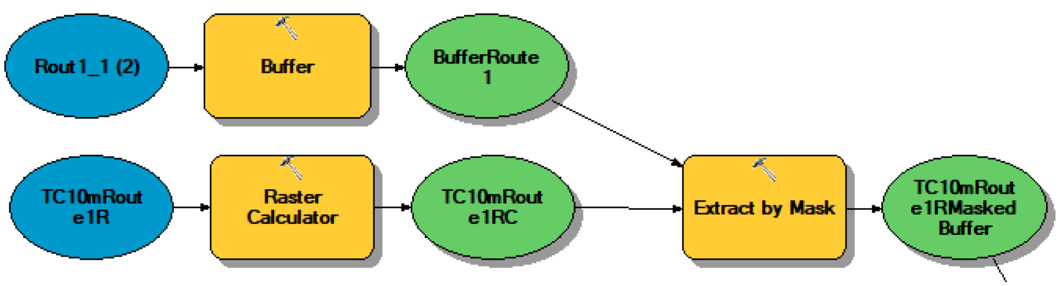

Figure 35- part of the model created in Model builder Arc toolbox in ArcGIS

Part of Created model for this project is shown in figure 35 and the entire model for this project is shown below in figure 36:

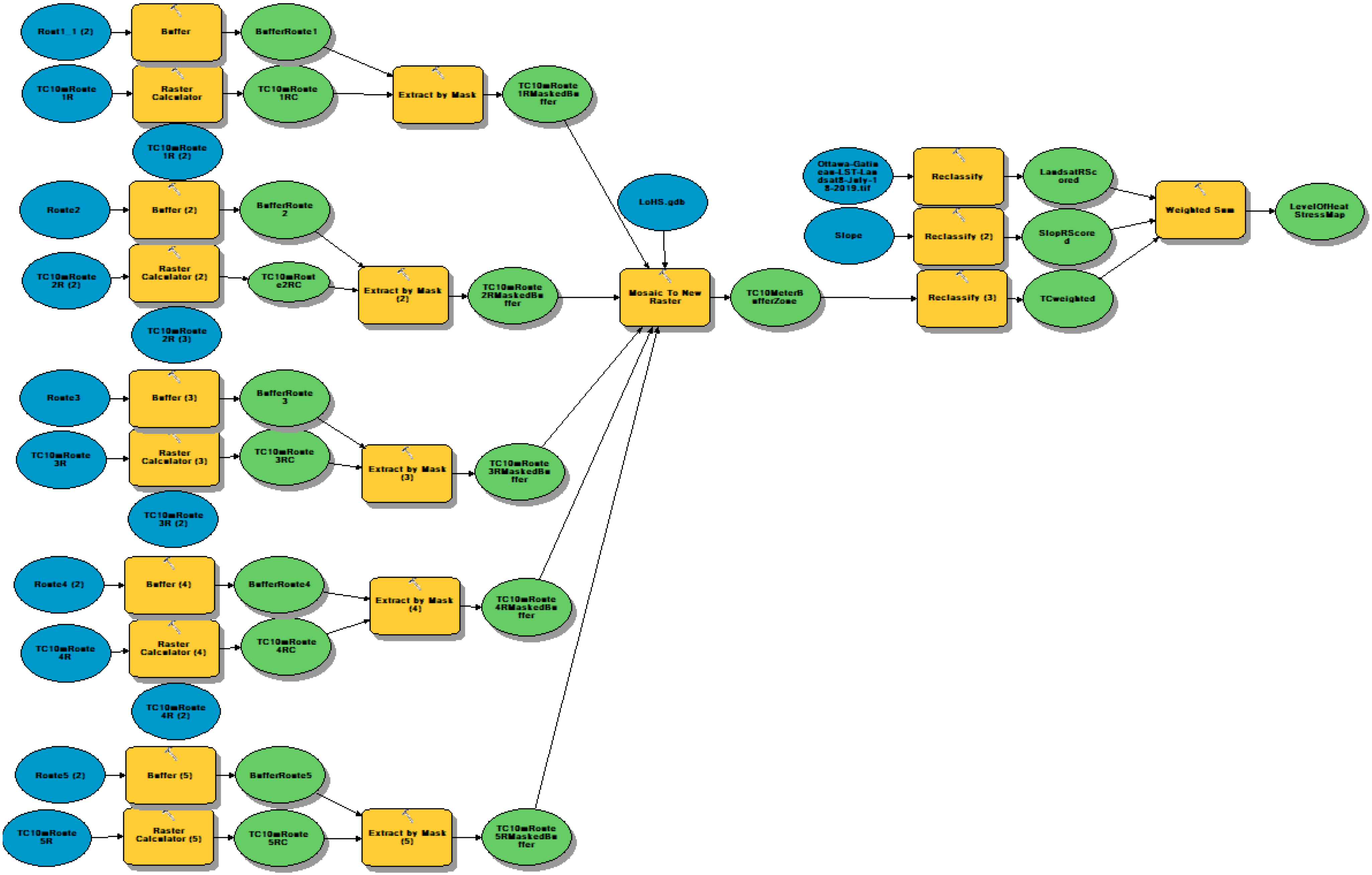

Figure 36- The whole model for this project in the model created in Model Builder (ArcGIS)

3.8 Process

The main process is the part that we do the index overlay method through "Weighted sum" tool. The Weighted Sum tool enables the user to weight and combine multiple maps and layers to create an integrated output. It is similarly does what the Weighted Overlay tool does by multiplying raster inputs, representing multiple factors, to combine layers by incorporating weights or relative importance. The main difference between the weighted overlay tool and the Weighted Sum tool is that in the Weighted Sum tool floating points are allowed values whereas the Weighted Overlay tool only accepts integer raster as inputs. So, in this project we used Weighted Sum tool. Weighted sum multiplies the designated field values for each input raster by the specified weight. It then adds all input raster together to create an output raster. The steps for running this tool includes:

1. Adding input rasters by clicking the Input raster drop-down arrow and select input raster and click Add. The raster is added to the Weighted Sum table. Repeat to enter other rasters as well.
2. Select field for each input raster by clicking the field column to specify the field to be used in the overlay analysis. The field must be a numeric field.
3. Assign weights for input rasters or assigned a percentage influence, based on its importance. For each input raster click on the weight column to specify a value. For this project the weights are equal which means all the studied features has similar influence on the final result. This amount of weights or percentage of influence can be changed by the user's purpose of doing the project which is the advantage of this method.
4. Run the Weighted Sum tool. In this step the cell values of each input raster are multiplied by the raster's weight. The resulting cell values are added to produce the final output raster.

3.8.1 Reclassification-Standardization

Before all the mentioned steps it is needed to standardize all the raters data. Because of the different scales upon which criteria are measured such as the slope is in degree, the Landsat values are in degree Celsius, and tree canopies are in meter it is necessary that maps be Standardized before integration by index overlay method since the type of data is different.. There are many methods for standardization including:

- Reclassification to a common scale (0-1(binary), 0-10, 1-5, etc.) for all types of variables (ratio, interval, ordinal, nominal).
- Transforming to Z (Normal standard score) if variable x has normal distribution. If not, x should be first transformed into a normal distribution then Z can be calculated for all types of variables (ratio, interval, ordinal, nominal). In equation (3.2) it is shown how to calculate Z value.

$$z = \frac{x - \bar{x}}{s} \tag{3.2}$$

- where $\bar{x}$= mean, S= standard deviation
- Calculating fuzzy membership values for the variable
- Applying "normalizing" formulas such as equation (3.3):

$$x_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{3.3}$$

using minimum and maximum values as scaling points. The simplest is a linear scaling for numerical variables (ratio, interval).

Among all mentioned standardization methods Reclassification to a common scale from 0 to 10 was used for all the rasters in this project.

It is essential to score data before running the model and combining layers through Weighted Sum tool to make them in one same measure to be comparable and become enable to weight them. Because we are looking for suitability map of cycling in terms of heat stress level our scores will be defined based on this fact. It is important to be aware of the advantage of this classification method which is being subjective. So, user can change this classification based on different purposes and different angle of view to the project.

Old values	New values
15.098928 - 19.751277	10
19.751277 - 21.0933	9
21.0933 - 22.166919	8
22.166919 - 23.419474	7
23.419474 - 24.761498	6
24.761498 - 26.103521	4
26.103521 - 27.445545	2
27.445545 - 28.787568	0

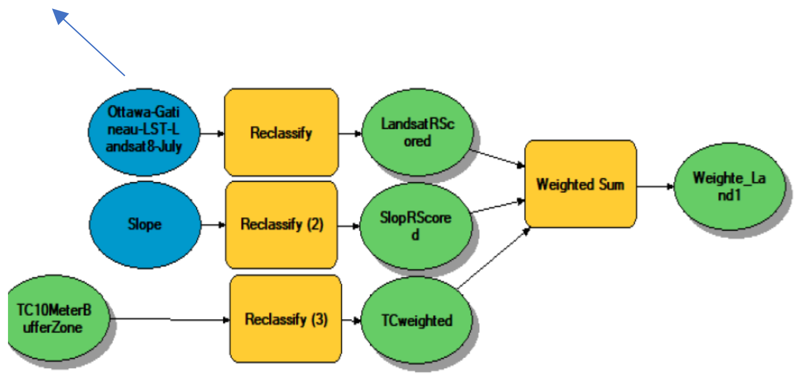

Figure 37-Landsat Reclassification

The classification for Landsat image was done based on the natural breaks (Jenk) (figure37) because natural breaks shows us the population of the values and it classifies the values based on the breaks that naturally exist in the data. This natural break shows the temperature classes with more meaningful visualization of map data and shows classes which boundaries are set where there are relatively big differences in the data values.

The classification for slope was done manually with 5 classes (Figure38). based on the literature review the break values for slope that cause rising human effort for cycling are 3% , 5% , 10%, 15% and more than 15%. Because our slope map was based on the degree we tried to identify those percentage in degree. So, our classes are 1.72, 2.86, 5.7 and 8.53

Old values	New values
0 - 1.72	10
1.72 - 2.86	8
2.86 - 5.7	6
5.7 - 8.53	4
8.53 - 87.930016	0

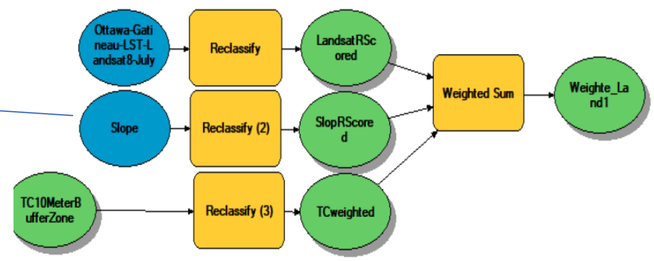

Figure 38- Slope Reclassification

The classification for tree canopies was done manually based on previous studies that shows the far the trees the less shade they have on the routes (figure39).

Old values	New values
0 - 2	10
2 - 4	9
4 - 6	8
6 - 8	5
8 - 10	3
NoData	NoData

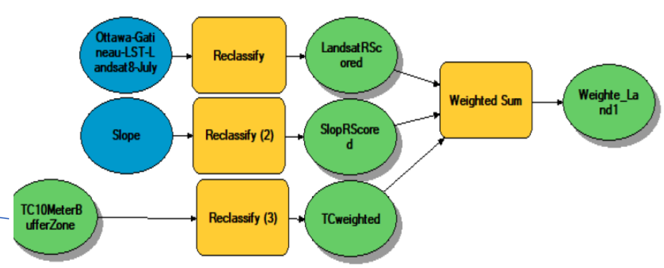

Figure 39- Tree Canopy Reclassification

3.8.2 Weighting

Assigning weights for input rasters or assigning a percentage influence is the last step before running the model, based on the rasters importance. Weighting in this step means showing how much effect each type of data could have on the final result. In many suitability analyses, some qualify properties are more critical than others. Usually, it is anticipated to reach a comparison after suitability analysis which can show how different criteria can affect the result and how strongly they can affect it. by assigning levels of importance to each criteria the integration can be extended. A numerical weighting factor is assigned to each criterion according to its relative importance compared to all other layers. Figure40 retrieved from http://www.gitta.info/Suitability/en/html/WeightOverla_learningObject1.html shows how numerical weighting is applied on Index Overlay.

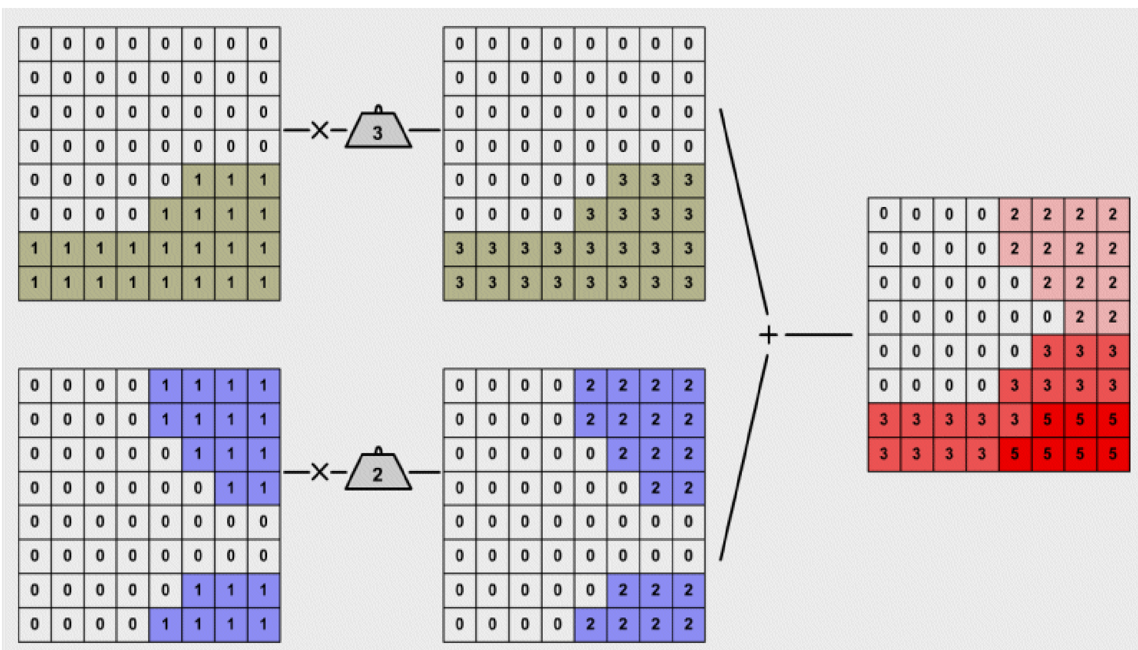

Figure 40-How weighting works in index overlay

This step will be done by user based on the purpose of the study. For example, if the final results is going to be used for tree planting purpose we can weigh the tree canopy effect more than others. So, by clicking on the weight column a value will be specified to weight each raster. For this project the weights are equal which means all the studied features has similar influence on the final result. Not to mention that this amount of weights or percentage of influence can be changed by the user's purpose of doing the project which is the advantage of this method (figure41).

Raster	Field	Weight
LandsatRScored	VALUE	1
SlopRScored	VALUE	1
TCweighted	VALUE	1

Figure 41- Weighting Criteria in the model created in Model Builder - Arctoolbox

3.8.3 Running the model

After building a model and checking that all processes are valid, the model is ready to run. Running a model in Model Builder means opening the model for editing and run it within the Model Builder window. Models can be run from within Model Builder. With running the entire model all the process will be done by just clicking on the Run button in the Model Builder run ribbon tab (figure42).

To run an individual model process that is not ready to run (gray), a warning message will display that the process is not ready to run. To run the entire model when it contains processes that are not ready to run (gray), any ready-to-run processes will run in sequence and processes that are not ready will not run.

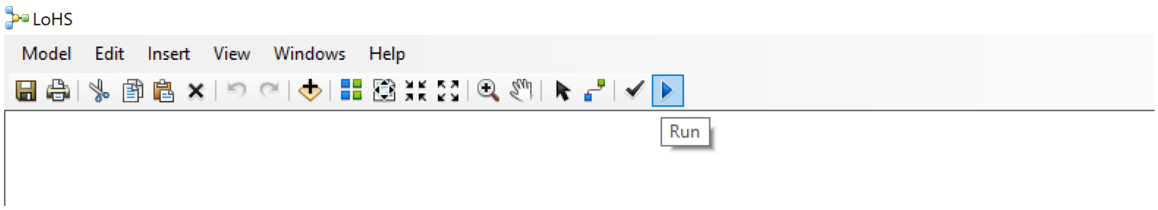

Figure 42- How to run the model created in Model Builder - Arctoolbox

It is possible to run a model step-by-step within a single tool or as a sequence of tools entirely within Model Builder as a geoprocessing tool from the Geoprocessing panel. If some tools have already been run, they are not re-executed; the model will begin executing from the first tool that has not yet been run (Figure43).

If the model will run step-by-step within a single tool, all processes up to the selected tool will run (earlier processes in the chain also run; later processes in the chain do not run).

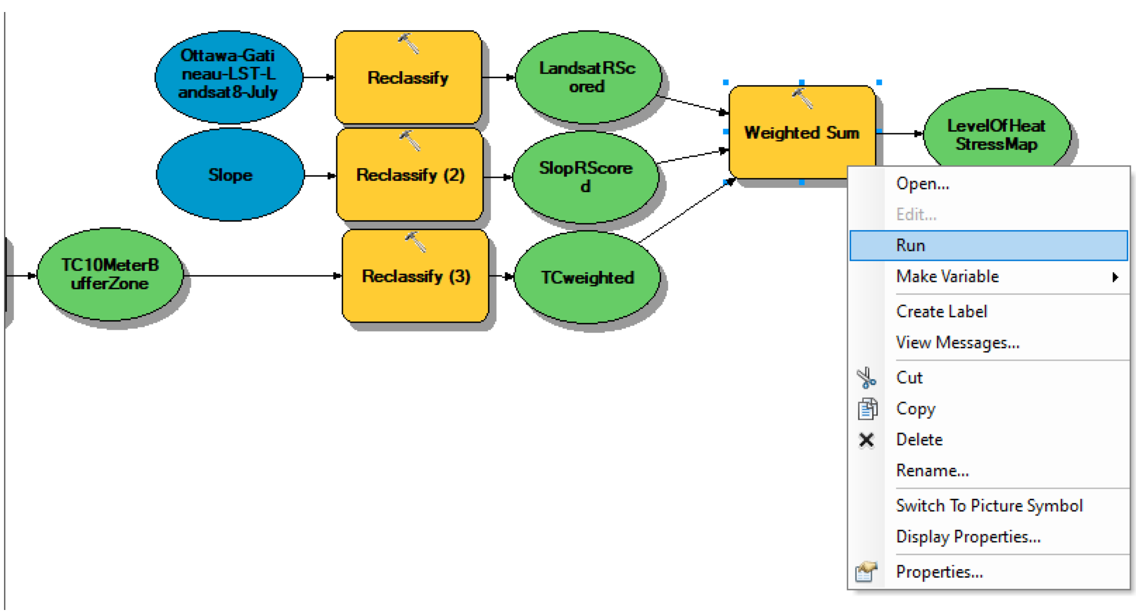

Figure 43-Running the model created in Model Builder - Arctoolbox

While the tools in the model are running, a progress window displays to indicate which process is running and any messages. As a model is running, the actively running tool is highlighted in red. Tools and outputs that are run successfully are displayed with a drop shadow (figure44).

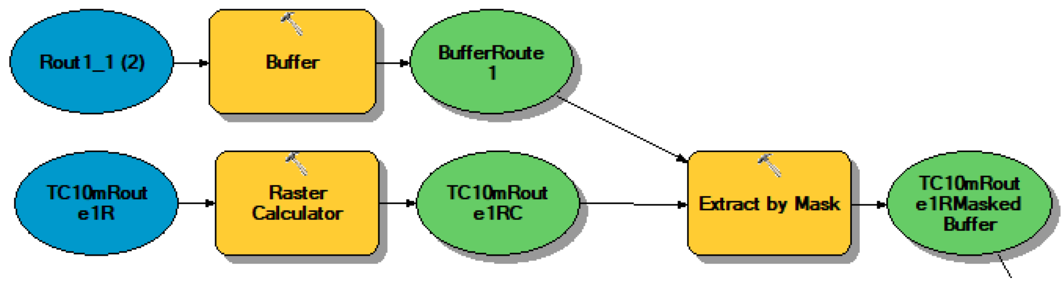

Figure 44- Model face after running in Model Builder - Arctoolbox

Any output variables that have been marked Add to Display will be added to the last active map (figure45).

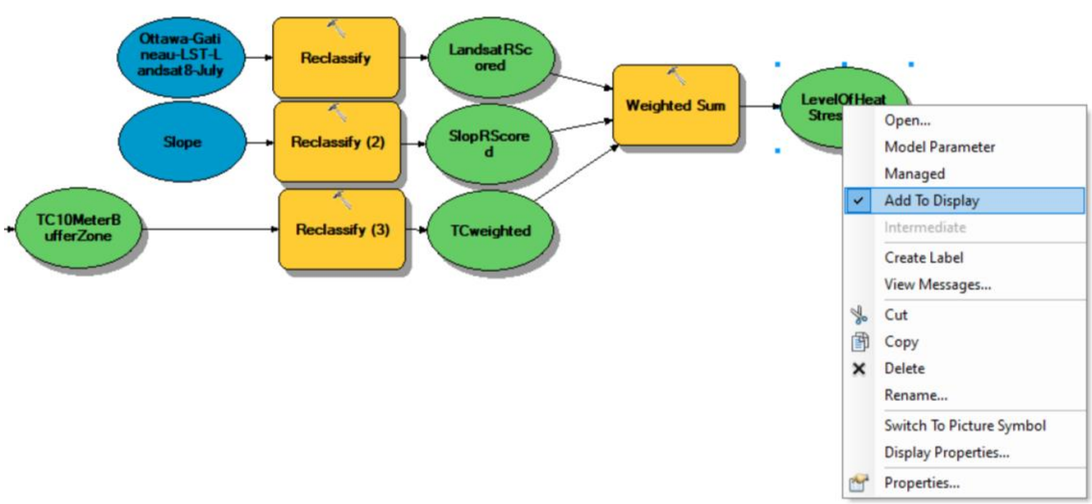

Figure 45- Add ran model to display

3.9 Result

Since index overlay method works by multiplying the designated field values for each input raster by the specified weight, it sums all input rasters together to create an output raster. As it is mentioned before it is used for suitability modeling. Overlay is one of the best methods to make an integrated analysis through a common scale of values to various and different inputs. Not to mention that, it is usually applied on multicriteria issues like site-suitability.

Because this study is looking for an integrated map to shows the ideal route out of the 5 sample routes, Overlay enable to determine the most ideal locations for cycling. In this integration process, it is supposed that the more desirable the factors, the more ideal the location will be. Therefore, the higher the value on the resulting output raster, the more favourable the location will be. It may be useful to find the second and third suitable sites determined by the model.

Equation (3.4) was used in the project index overlay method.

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \tag{3.4}$$

Each class of any maps is given a different score. The score range is between 0 – 10 range.

Based on reclassification that has been done in this project which closer to 10 is "cooler" areas so more suitable, in the final maps larger value pixels must be more suitable. Except the visual comparison that are available through produced map by the mentioned Index Overlay method there is another method to compare the results of the routes by getting profile of the them. This tool Creates a table and optional graph denoting the profile of line features (in this project is the sample routes) over one or more raster (the suitability map in terms of heat stress level in this study).

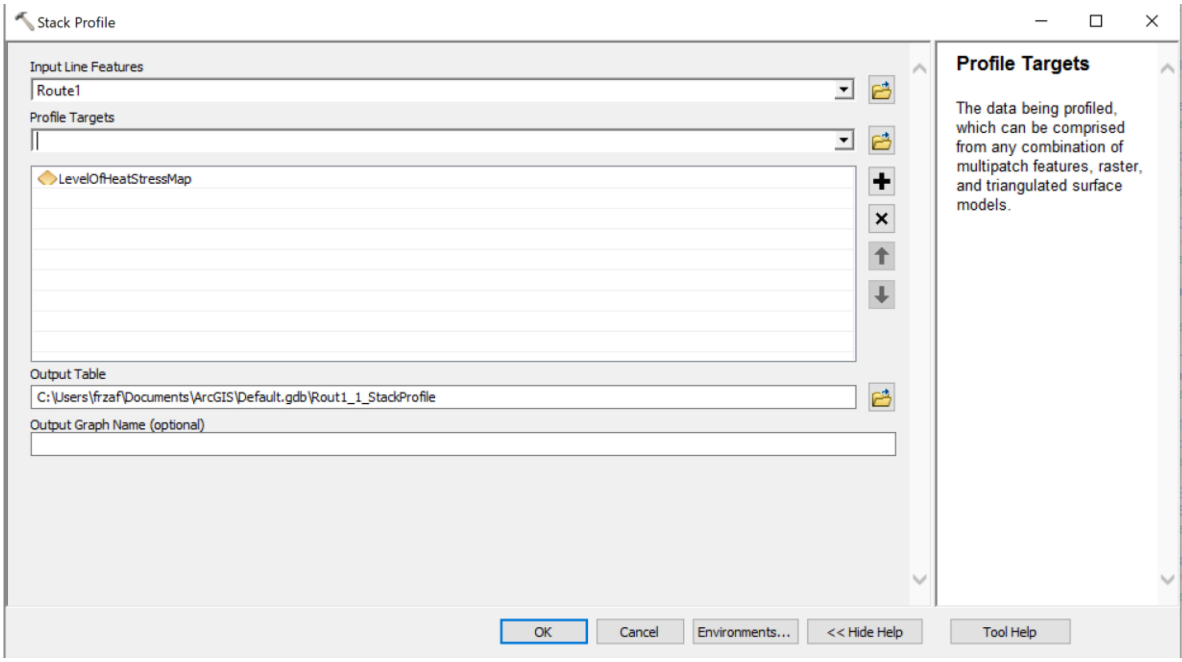

Figure 46-Getting profile of the suitability along the trail-ArcMap

So, it enables user to compare the results by profile and give it numerical values of the suitability level for the pixels along the trails and calculate the average of the amounts to have a better understanding of suitability (figure46). Having the numerical values of the suitability level for routes, the number of times it hits the maximum suitability value or minimum suitability value and other statistics can be calculated in other software such as Microsoft Excel, R, MATLAB, etc.

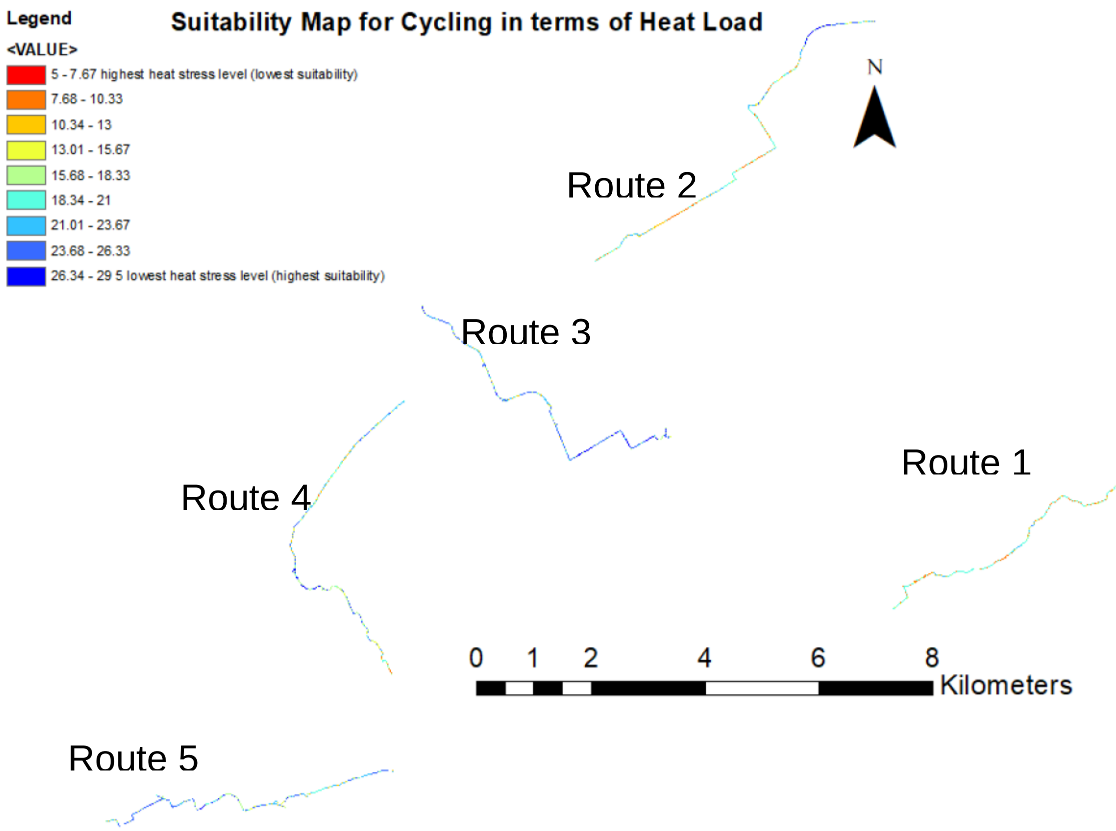

Figure 47- Cycling Suitability Map for all sample routes in terms of Heat Load

Route 1:

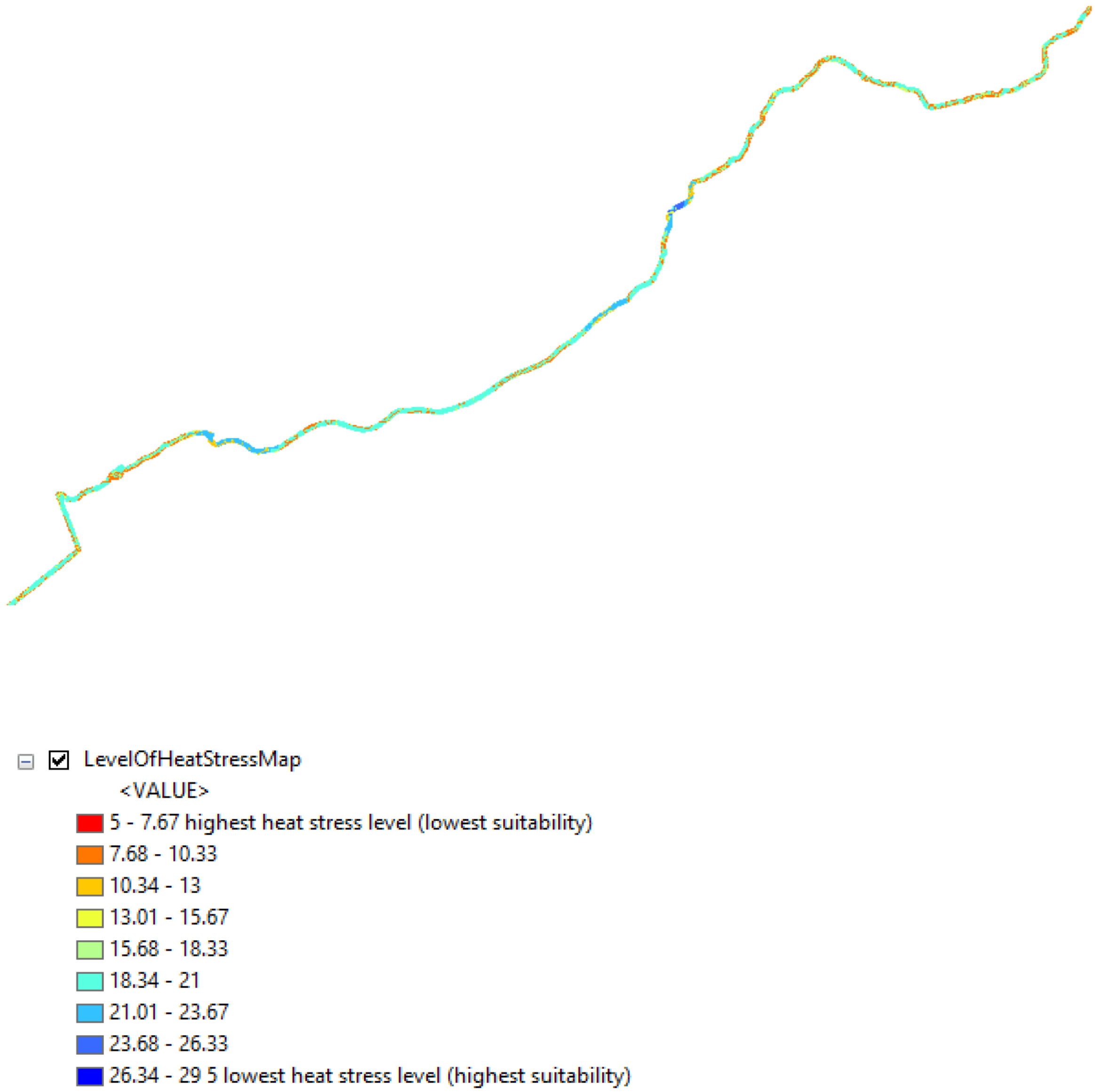

Figure 48- Route 1 suitability map

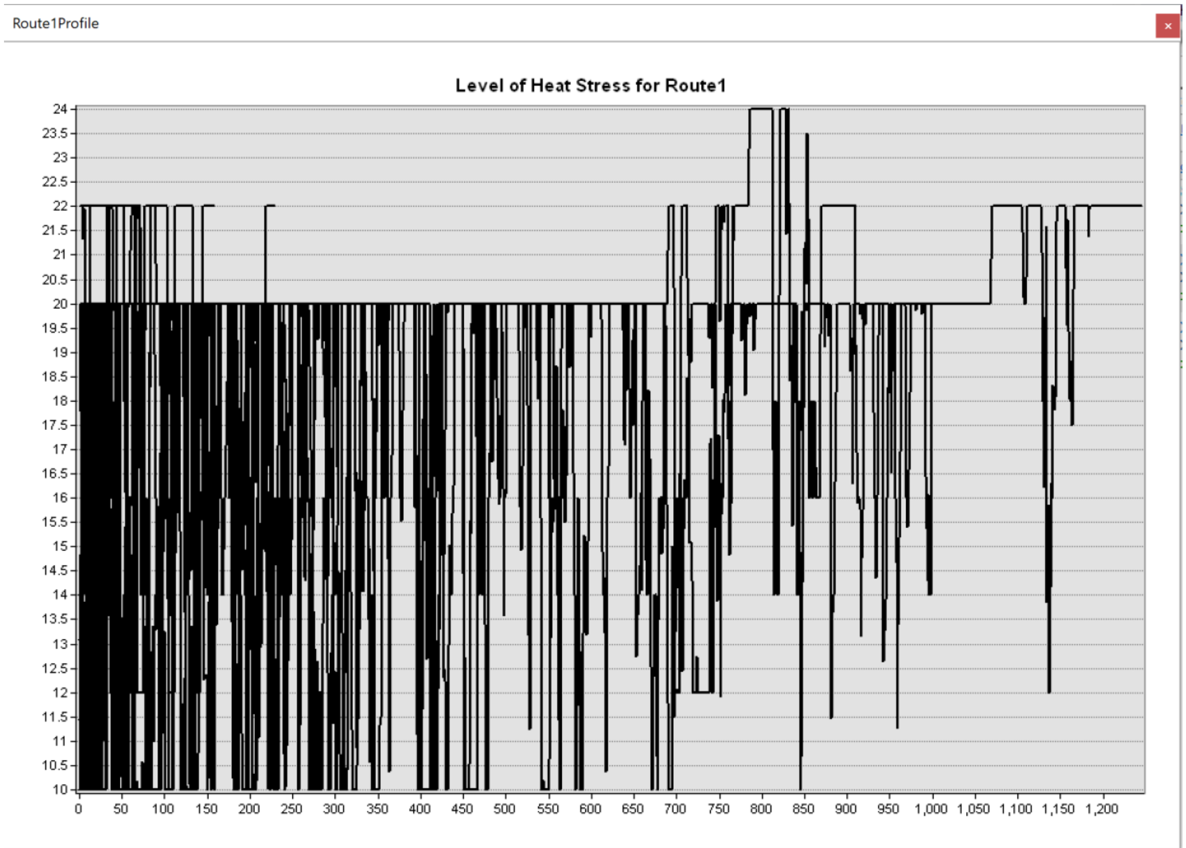

Figure 49- Route 1 suitability profile

Route 2:

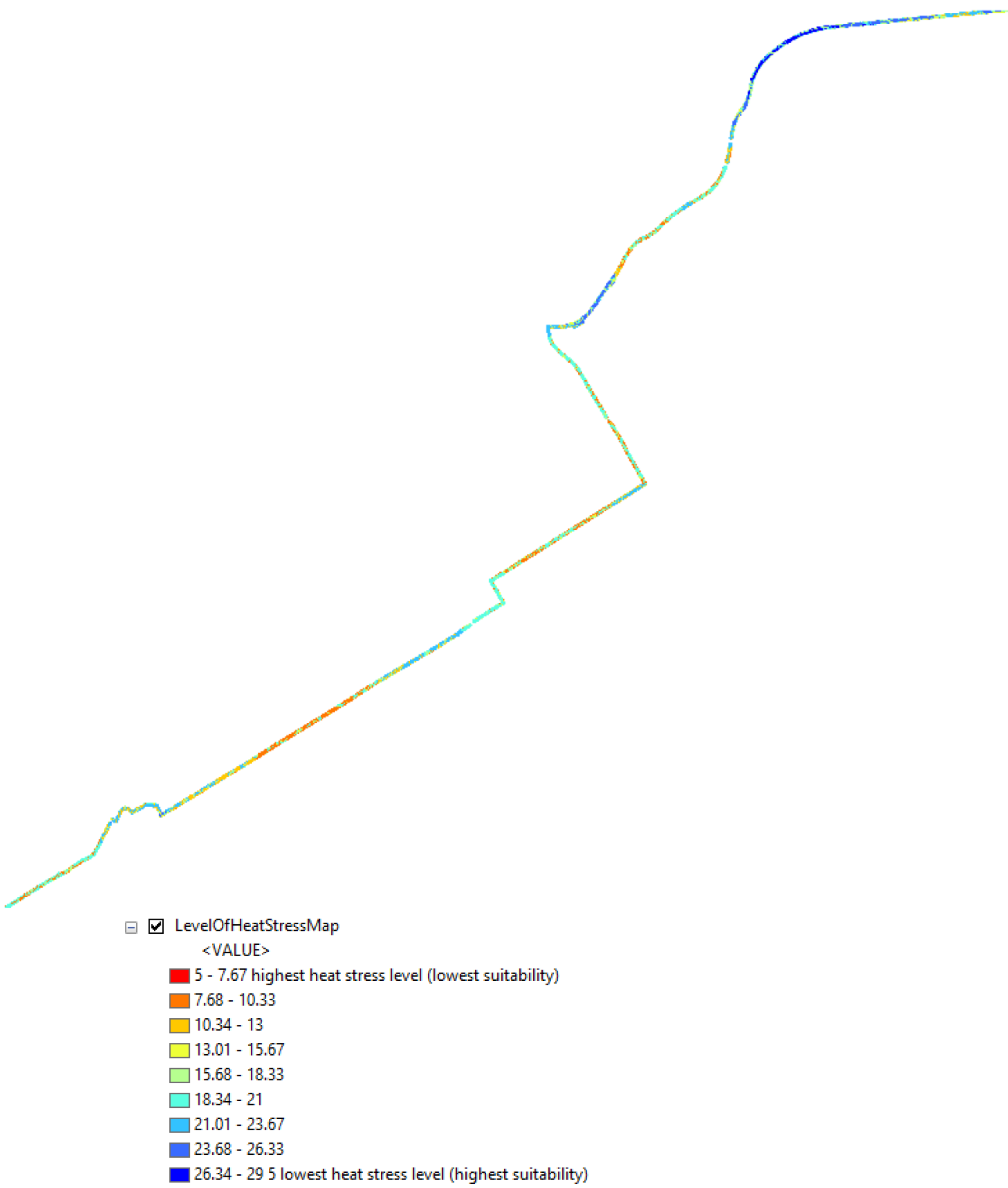

Figure 50- Route 2 suitability map

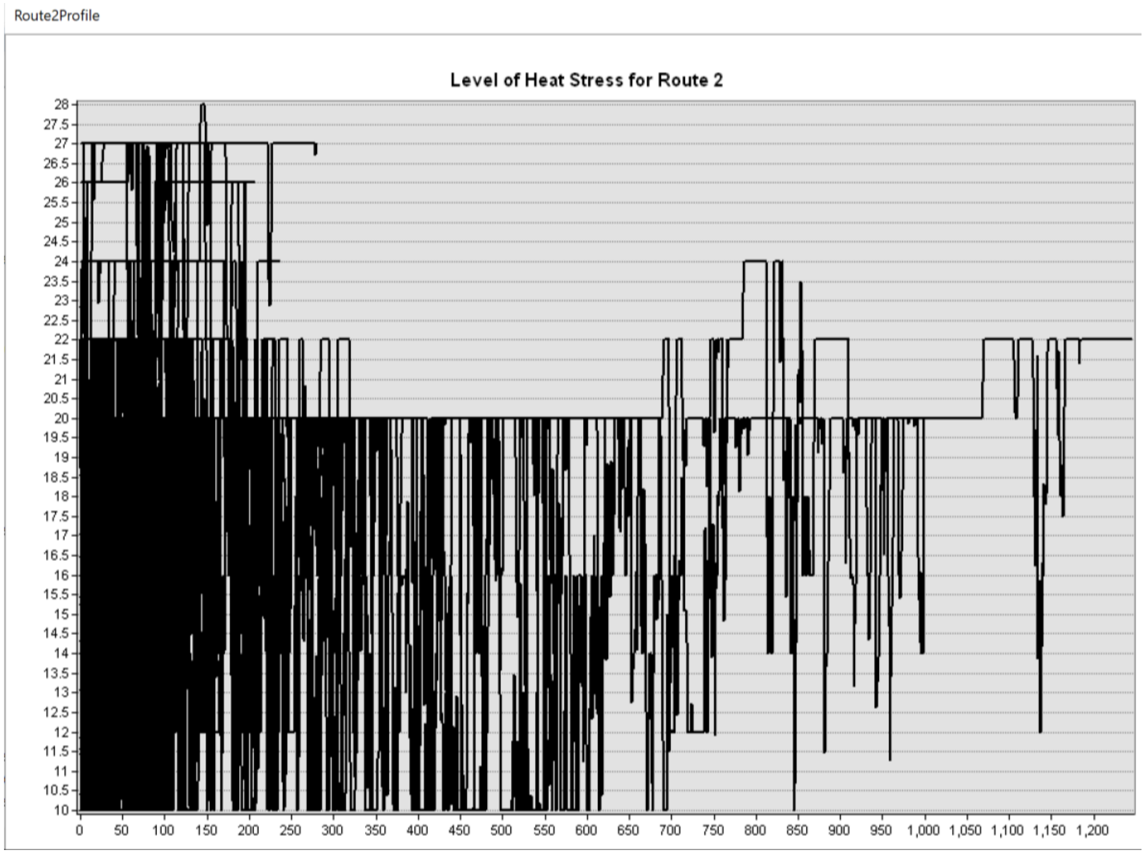

Figure 51-route 2 suitability profile

Route 3:

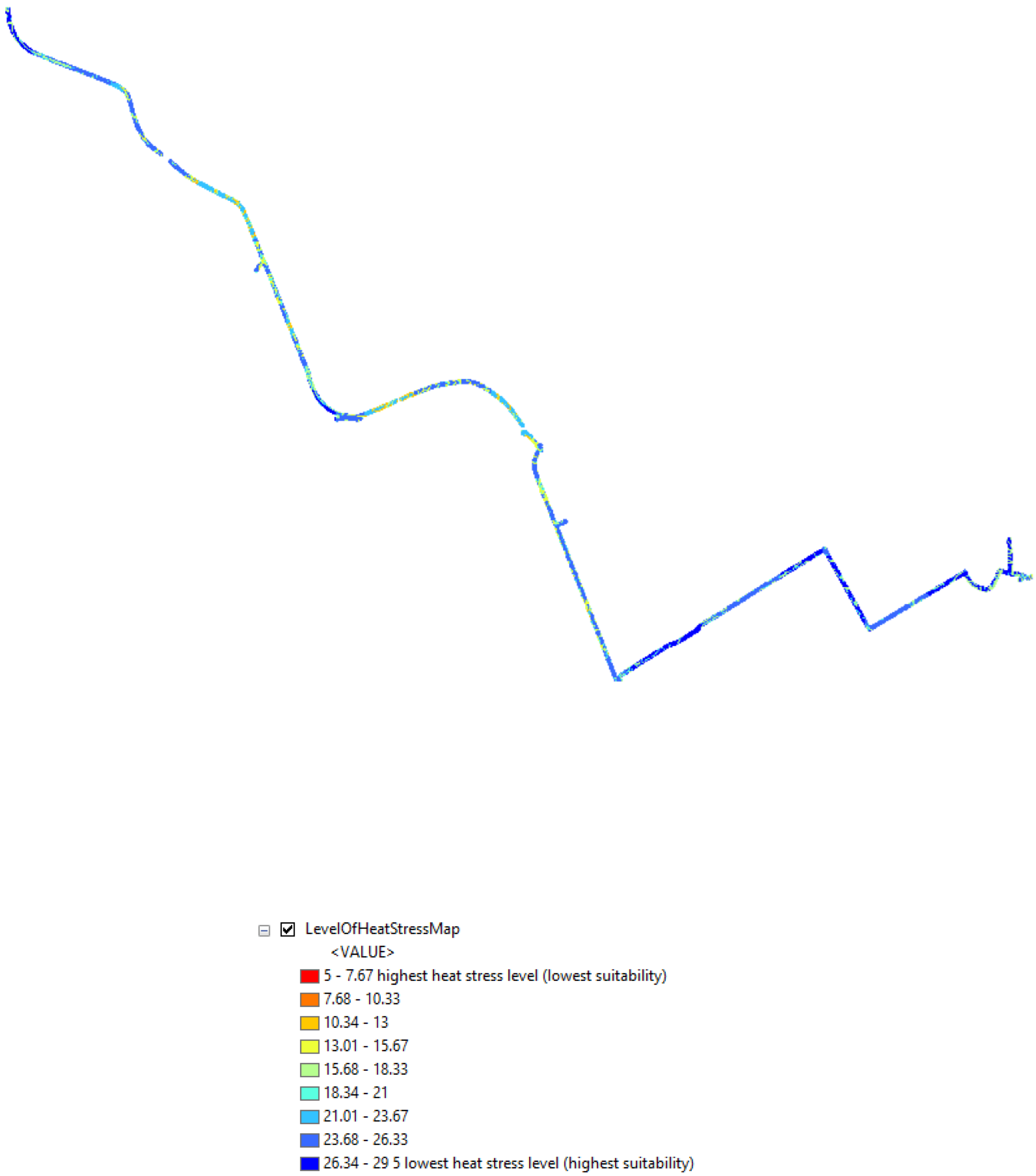

Figure 52- Route 3 Suitability map

Route3Profile

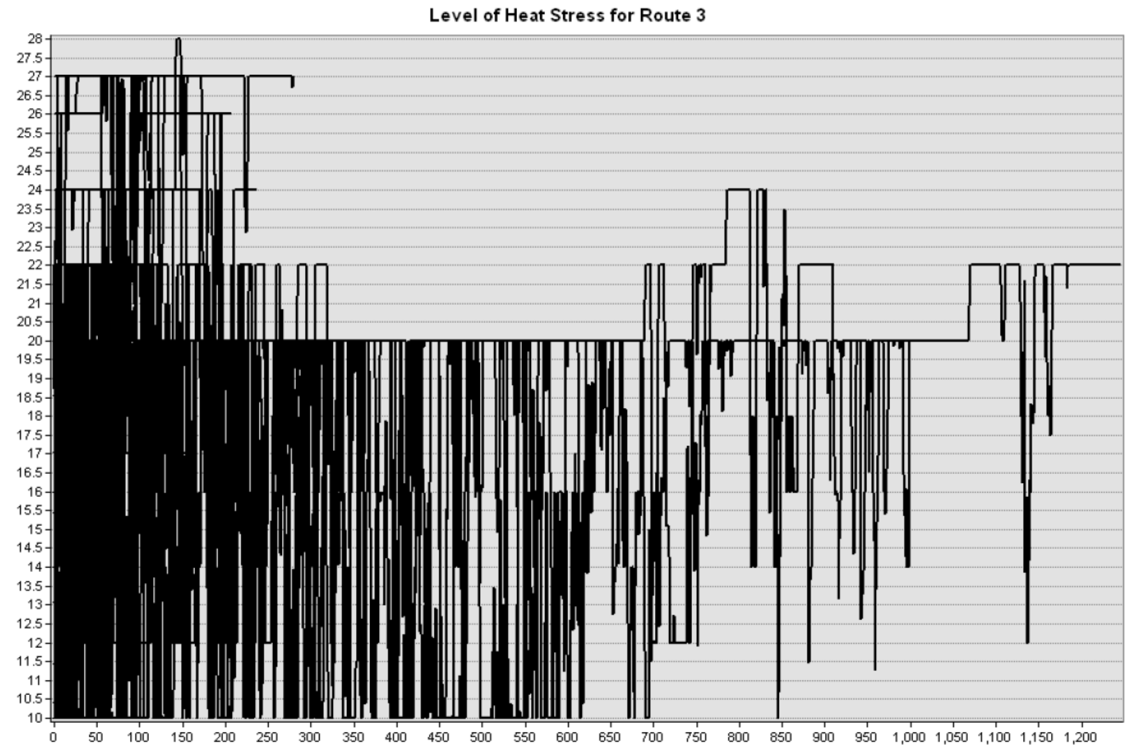

Figure 53- Route 3 suitability profile

Route 4:

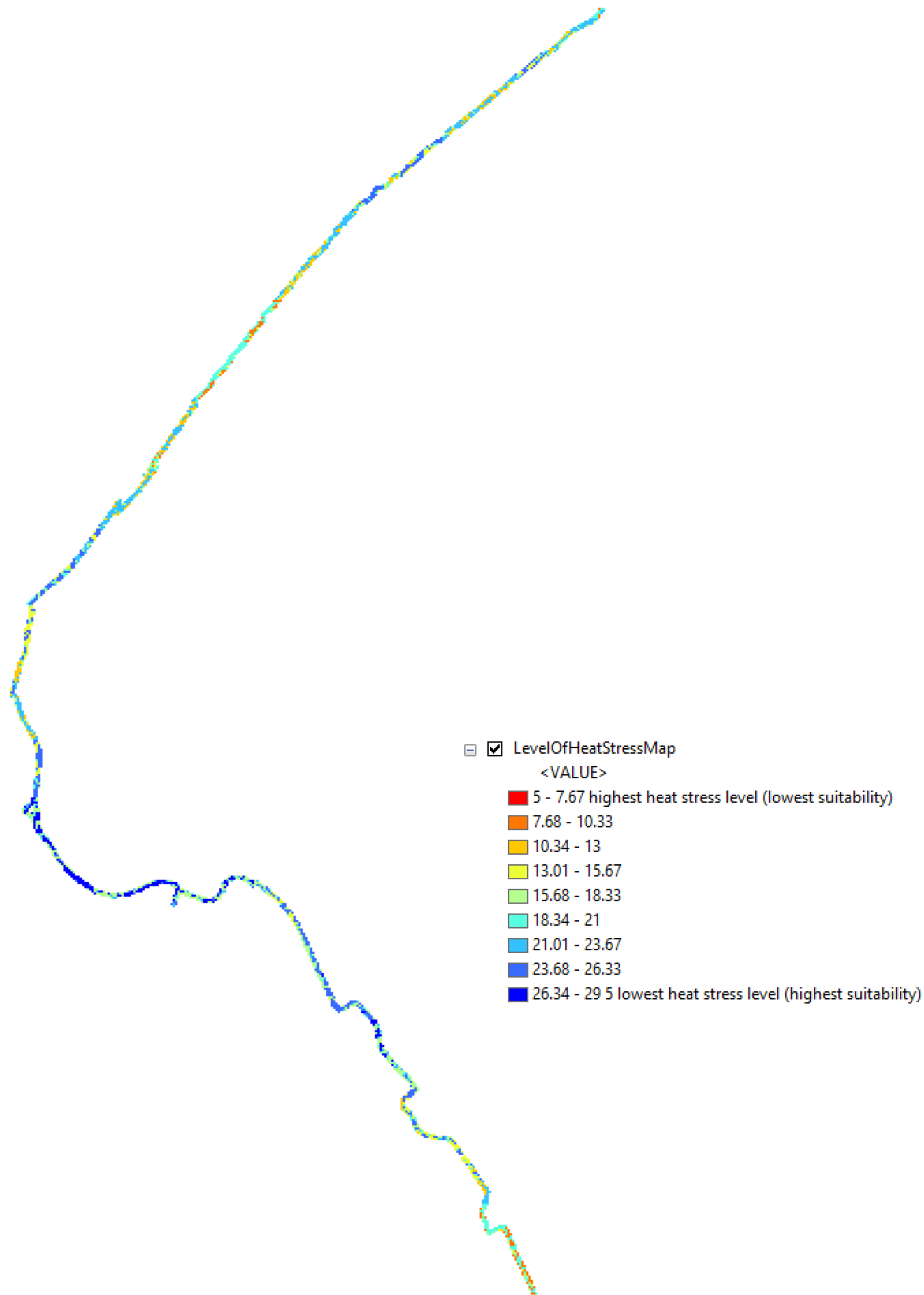

Figure 54 - Route 4 suitability map

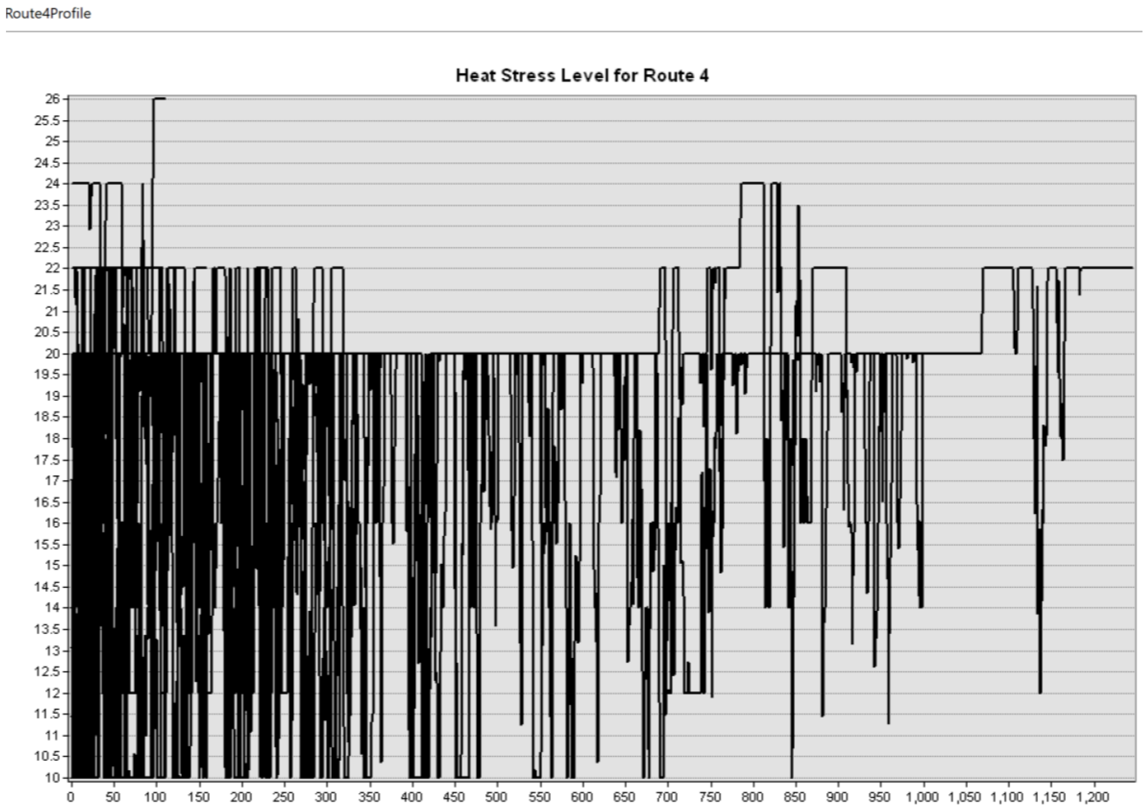

Figure 55- Route 4 suitability profile

Route 5:

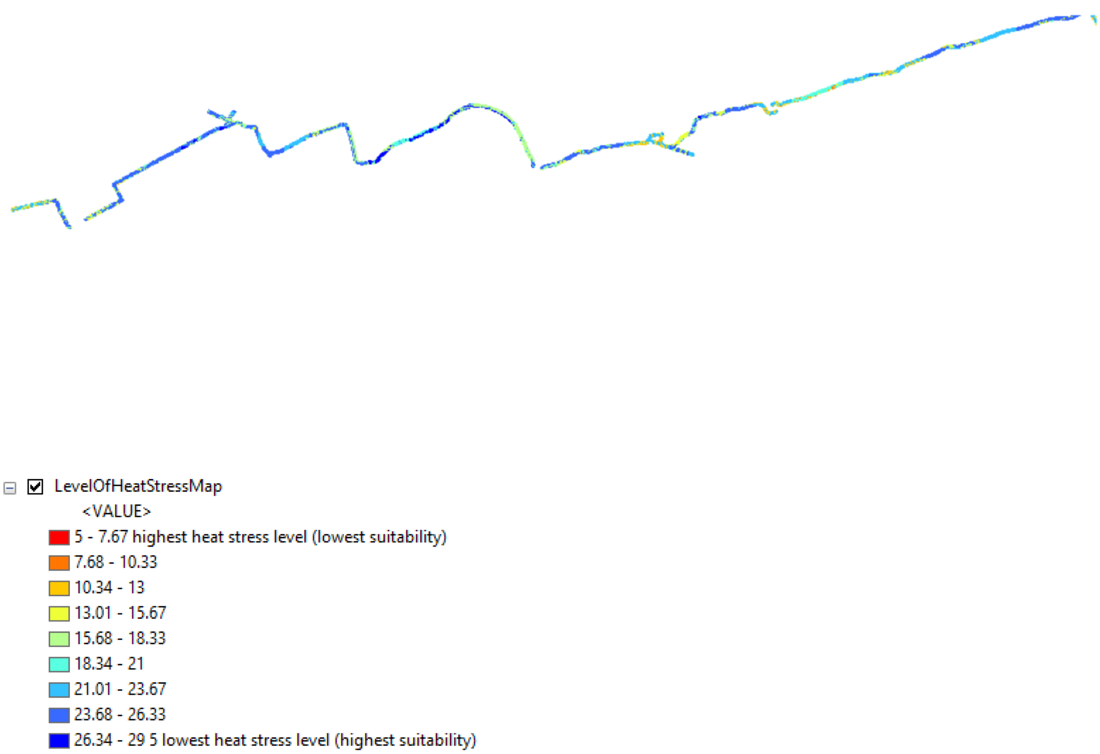

Figure 56 - Route 5 suitability map

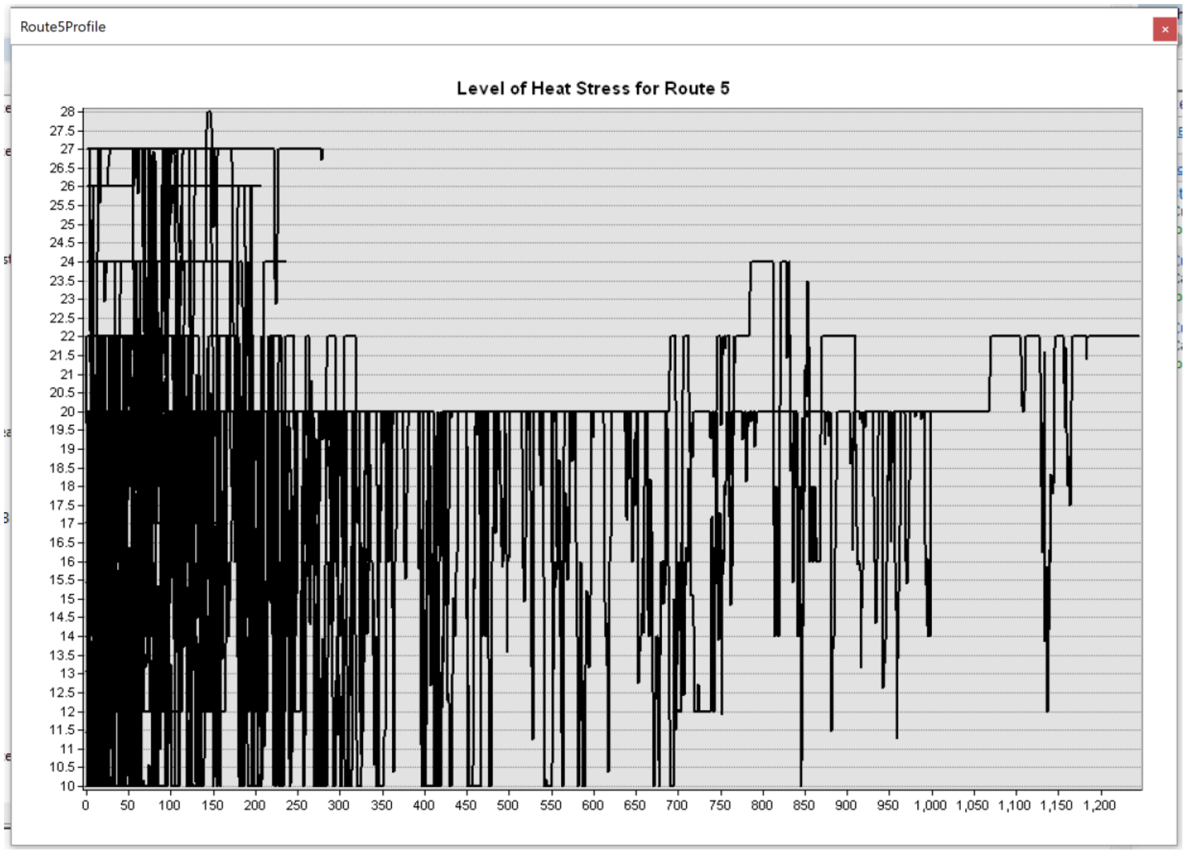

Figure 57- Route 5 suitability profile

Considering maps for all routes and their heat load profile including figure47 to figure57 it is revealed that route 3 has less heat stress level along the route compare to others which means it is the most suitable route between the 5 for cycling, running or walking in terms of having more shaded area, less slope and less heat island effect. This integration process is based on the most desirable factors which ends up in the most suitable areas. So, higher values in the result output raster, shows more suitability of the location. Based on this the heat load profile of route 3 shows that it hits the maximum suitability values which are between 18 to 30 many times more than other route's profiles. Since the range of suitability is measured between 5 to 30 by the Index Overlay tool some areas along the way get values which means their suitability are lower and some areas get higher value which shows they are cooler areas. The average of the suitability amount along the way

for this route is 22.87 which compare to the other route’s average of the suitability amount is the highest average number of suitability along the way.
It is also important to find the second and third suitable sites determined by the model.

As it was mentioned before, stack profile tool enables user to compare the results by profile and tables including some numerical values of the suitability level for the pixels along the trails. Having the numerical values of the suitability level for routes, the average of the average of the suitability amount along the routes has been calculated to have better idea of the most suitable route with the least heat stress level.

Comparing the integrated maps virtually, by their profile and by the average amount of suitability along the ways, route 5 has the highest suitability after route 3 and it has less heat stress level compare to the others with the suitability average amount of 21.96 and then route 4 with the suitability average amount of 20.82 , route 2 with the suitability average amount of 18.87, route 1 with the suitability average amount of 18.36 are the ideal routes for cycling in order. This suitability average amount confirms what is illustrated by the maps visually.

3.10 Conclusion

To conclude this section, it was shown that the Index Overlay Method which was proposed to this major research project is performing as anticipated and it meets the conceptual methodology's objectives, requirements and specifications. Current findings suggest that among all sample routes for cycling, running and walking that were chosen by experts considering different criteria, the one which has the highest average suitability or is shown with more blue color in the map is the most suitable and ideal trail for doing those sport activities in terms of having less heat stress level which is the Decision making step in the work flow as it is marked in the figure 58.

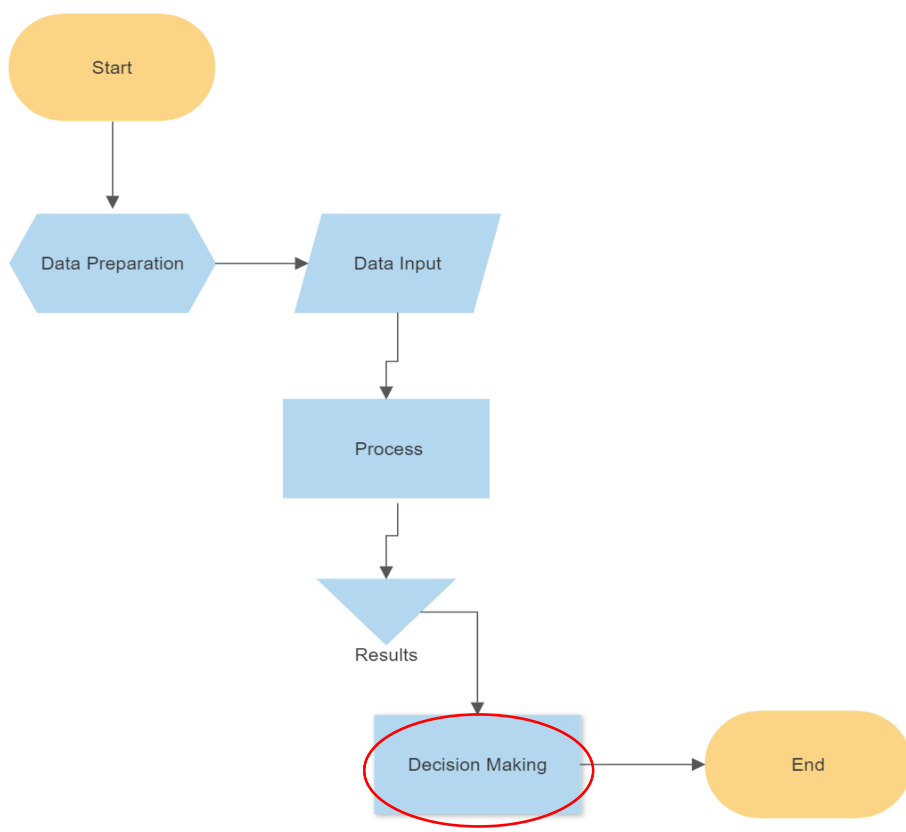

Figure 58- Workflow

At the process phase it was shown that it is needed to standardize all the rater data. So, reclassification for raster has been done to a common scale of 0 to 10.

The classification for Landsat image has done based on the population of the values and classification of the values was done based on the breaks that naturally exist in the data from 0 to 10.

The classification for slope was done manually with 5 classes and the break values for slope that cause rising human effort for cycling were 3% , 5% , 10%, 15% and more than 15%.

The classification for tree canopies was done manually based on previous studies that shows the further the trees the less shade they have on the routes.

Addition to reclassification weighting was done in this step which shows how much effect each type of data could have on the final result. This step will be done by user based on the purpose of the study. After building the model and checking that all processes are valid, the model was run.

These were the main steps that were done by the user based on its purpose and objective of the project. Therefore, there are several improvements and additions that could be brought to such a project in order to get the different result based on the purpose of the study which will be discussed in the next chapter.

4. Chapter 4- Discussion and future studies

4.1 Discussion

The present research project was planned to provide convenient infrastructures that are needed to help resident's safety stay active outdoors during high-heat events. Using GIS which has always been an integrated tool that could analyze the accessibility plans enabled the researcher to take advantage of analyzing collected data concerning their importance and allowed carrying out complex assessment of the situation and provide suitability map and creates a basis for applying of more exact and scientifically influencing features, tools and methods for future application and studies.

The literature review revealed that vulnerability, disease and mortality are expected to rise due the heat excess and the average temperatures which are creeping up. So, on heat events in summer most travellers tend to decrease their energy usage during cycling and select the ideal routes for cycling in terms of weather condition, facilities, traffic, hilly topography, shady areas and temperature. Specially between similar routes from distance aspect travellers prefer choosing the path that needs fewer physical activities that is caused by the sharp slope. They tend to choose the route which they sweat less while they are cycling along that way which is caused by direct sun light.

Among many elements and aspects that can affect decision makers to choose the route and time of their walking, running and cycling including topography, climate, presence of bicycle facilities, traffic conditions and cycling infrastructures, 3 major features affect their decision more than others including: Topography, Shaded areas, and temperature which caused by Heat Island Effect (HIE).

With this research, the effort was put on establishing an integrated map that shows the suitability of 5 sample routes for cycling, walking and running. This method can be applied to cover the whole city of Ottawa and Ottawa's cycling network in the future and it will help travellers to decide of taking trails for cycling based on the effort and the heat load that they feel along the way. The final map is a guidance based on minimizing heat load (suitability map for cycling). It can be a transportation planning analyser for municipality to have a new urban planning metric which can Identify existing, and planning future ‘shade corridors’ for pedestrians and cyclists by prioritize tree planting.

Current finding suggests that 3 mentioned major factors including Topography, Shaded areas, and temperature which caused by Heat Island Effect (HIE) has equal impact on the result. That means these factors weighted equally in the process. However, this weighting system can vary for different purposes and objectives of the project. For instance, the user who is looking for more “shade corridors” for planning tree planting may increase the weight of shaded area factors which extracted from tree canopy data.

Therefore, there are several improvements and additions that could be brought to such a project in order to get the different result based on the purpose of the study.

4.2 Benefits

This study has the potential to improve decision making practices. Multiple benefits are identified at this point of time. Previous studies discussed the impact of each criteria’s such as slope, shade and heat island effect (HIE) on the cyclists’ decision making separately. None of them integrated these factors together similar to this study. This study illustrates the positives of using GIS in decision making.

- It suggests a planning analyser which travelers can make decision of taking routes for cycling based on the effort and energy required and the heat load they will experience due to the sunlight or HIE.
- It leads to the projects that identify existing ‘shade corridors’ for pedestrians and cyclists and planning tree planting projects.
- It can also end up to a new urban planning metrics.

- It will be a platform to stablish an AI-powered application that helps the travellers in decision making of taking travelling route based on different factors such as temperature, climate condition, slope, distance, shaded areas, etc.
- The app would eventually be distributed as one of the municipalities freely available applications. It would allow residents to quickly receive recommendation about which route is currently the ideal based on their feature preference such as weather, temperature, slope, etc.

4.3 Future studies

Geographic information system (GIS) is something that is used by researcher and planners everyday to develop, plan, analyze and fallow the procedure of their plans. It provides a better understanding and a big picture of tomorrow to transfer it to today's plans for researchers and developers to facilitate their decision making progress.

Rapidly climate change is threatening the public health which is needed to be carried out and the relevant needs of residence should be considered as well. Information technology, especially GIS, has proven in helping cope with this issue. Software tools and solutions are helping with planning and meeting these demands. Using GIS software and its toolbox, help tasks perform more efficiently.

At first it seems simple to design the ideal infrastructures for community and ensure the methodology supports the design objectives, but reality is far more complex. Therefore, future possibilities exist with this study.

Firstly, Statistics, reports, articles, satellite images, maps and drawings all aid in understanding the planning area and its problems. Alternative solutions may be developed based on the available data by importing them into the models. So, other parameters than what we considered in this research project such as Wind Direction, Distance to the River, Lakes and Water, the Trails' Cover (Asphalt, Concrete or soiled ways have different temperature and various amount of reflection and absorbing sun light), Human heat stress response, etc., could be counted in the system and would highly benefit the result.

Secondly, these models predict, for example, the heat load changes along the way or simulate the suitability of the trail. Although GIS facilitate models by providing digital geo-data and display of intermediate and final results, usually these computer models are implemented as stand-alone software because some data such as tree canopy maps are not updated online, and they are updated regularly for example once per year. So, achieving at the most appropriate solution requires collaboration among many stakeholders, finding the latest updated data and additionally using spatial temporal data that states changes during the time to achieve the most accurate values for the samples that are not available online and are collected regularly such as Landsat images which shows the HIE but it is captured every 16 days from the same location.

Thirdly, there are other methods of standardization rather than reclassification to a certain scale which was done in the process section of this project including below methods that can be applied on the same model for future studies and compare the final results and study the impact of standardization method on the final maps:

- Reclassification to a common scale (0-1(binary), 0-10, 1-5, etc.) for all types of variables (ratio, interval, ordinal, nominal).
- Transforming to Z (Normal standard score) if variable x has normal distribution. If not, at first x should be transformed into a normal distribution then Z can be calculated with equation (4.1) for all types of variables (ratio, interval, ordinal, nominal)

$$z = \frac{x - \bar{x}}{s} \qquad (4.1)$$

where $\bar{x}$= mean, S= standard deviation

- Calculating fuzzy membership values for the variable
- Applying "normalizing" formulas such as equation (4.2):

$$x_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \qquad (4.2)$$

using minimum and maximum values as scaling points. The simplest is a linear scaling for numerical variables (ratio, interval).

Finally, the model can be solved with different method of integration such as process modeling which uses equations to integrate the maps and compare the result with the index overlay method.

To conclude, it is illustrated in this research project that GIS can provide models and interpretation easier for solving the problem and give a better understanding of what the user is looking for which may otherwise not be easily achievable by other methods to fulfill the needs of public health. This project can be a platform for future studies to create an application and a planning analyser that helps the travellers in decision making based on their concerns related to the heat stress.

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