ASERS

Journal of Environmental Management and Tourism

Quarterly
Volume XIII
Issue 5(61)
Fall 2022
ISSN 2068 – 7729
Journal DOI
https://doi.org/10.14505/jemt

ASERS Publishing

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ASERS Publishing
http://www.asers.eu/asers-publishing
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DOI: https://doi.org/10.14505/jemt.13.5(61).22

The Investigating Water Infiltration Conditions Caused by Annual Urban Flooding Using Integrated Remote Sensing and Geographic Information Systems

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Suggested Citation:

Trigunasih, N.M., Saifulloh, M. (2022). The Investigating Water Infiltration Conditions Caused by Annual Urban Flooding Using Integrated Remote Sensing and Geographic Information Systems. *Journal of Environmental Management and Tourism*, (Volume XIII, Fall), 5(61): 1467 - 1480. DOI:10.14505/jemt.v13.5(61).22

Article's History:

Received 14th of May 2022; Received in revised form 7th of June 2022; Accepted 31st of July 2022; Published 2nd of September 2022.

Abstract:

Flood disasters always hit densely populated urban areas during the rainy season. The causes of flooding that will examine in this scientific article are the condition of water infiltration into the soil. The case study was conducted in the urban area of Denpasar, Bali, Indonesia. Remote sensing data derived from various satellite images *i.e.*, Sentinel-2 (BSI and NDVI extraction), Alos Palsar Imagery (slope extraction), CHIRPS (annual rainfall), and soil texture by laboratory analysis. Acquisition of remote sensing data using a Cloud Computing platform named Google Earth Engine (GEE). Data analysis using weighted overlay with ArcGIS 10.8 and threshold classification using natural breaks (Jenks). Denpasar City has the potential for water infiltration is good to very critical conditions. The correlation of the water infiltration map was carried out by comparing flood events in Denpasar City. The correlation results show (R^2 = 0.84), (r = 0.916), (RMSE = 0.138), and p-value <0.05, these values indicate very high relation. Flood events often occur in zones with very critical water infiltration with high building density and low vegetated land cover. The condition of water infiltration critical to very critical category, spatially at the proportion of land cover vegetation < 1% and built-up area > 37%.

Keywords: infiltration; flood; remote sensing; Geographic Information System (GIS); Landuse/ Land Cover (LULC); urban area.

JEL Classification: Q25; Q55; R11.

Introduction

Water is a natural resource that has an essential role in the life of living things, especially humans. However, this makes a fundamental problem in everyday life due to the lack of water availability, without realizing that this problem has been happening for a long time. The longer the intensity and the greater the frequency, increasing from time to time with the growing population, expansion of residential areas, the opening of new land, development of the industrial regions, and others. The use of water, especially groundwater, which increases continuously, can harm the groundwater itself and the environment (Nguyen *et al.* 2019; Sim and Balamurugan 1991; Rimba and Yastika 2020; Chen, *et al.* 2020). If the quantity and quality of groundwater decrease, it will have a negative social, economic and environmental impact. The use of groundwater that continues to increase must be accompanied by good management planning. This is because if the use of groundwater on a large scale but not balanced with good groundwater resource management, then gradually, the existence of groundwater will be increasingly extinct from the face of this earth and will have a destructive impact on the survival of all living things (Albert *et al.* 2021; Beqaj and Çobani 2021).

A water recharge area is where rainwater seeps into the ground, which then becomes groundwater. The infiltration process plays an essential role in replenishing soil moisture and groundwater. The infiltration process is flowing water from rainwater into the ground. Water catchment areas in urban areas are critical, and these water catchment areas are considered very important to preserve groundwater resources and create a balance of environmental water resources (Somers and McKenzie 2020; Condon *et al.* 2020).

Suppose the land that functions as a water catchment experiences a continuous decline. In that case, it will cause various ecological problems, such as the high volume of surface runoff water. If the amount is more significant than the catchment discharge of the watershed in the area, it can result in local flooding (Condon *et al.* 2020). Besides being able to cause local flooding during the rainy season, which often occurs in the city of Denpasar (Adisanjaya *et al.* 2021; Kusmiyarti *et al.* 2018).

The problem of flooding in Denpasar City is caused by high rainfall and several other factors such as land slope, area elevation, land conversion, poor drainage system, and community waste (Kusmiyarti *et al.* 2018).The causes of flooding include very high rainfall (> 50 mm/day), sloping topography of the city, decreased infiltration of rainwater into the soil due to a large number of built spaces, inadequate drainage capacity, and poorly maintained drainage channels (narrowing, silting and drainage). Blockage by garbage) and the lack of green open space, especially in West Denpasar District because it only covers 524.20 ha or 21.72% of the total area of Denpasar City. The analysis of water infiltration was carried out to minimize the occurrence of inundation floods in the Denpasar urban area.

Integrated of remote sensing and geographic information systems (GIS) can analyze these problems through satellite imagery and geospatial data (Saha and Agrawal 2020; Domakinis *et al.* 2020). The novelty of this research is about the type of data used. Research on the potential for water infiltration has been carried out in various urban areas and watersheds in Indonesia. The first water recharge area identification was initiated by Wibowo (2006) and legally explained in the Minister of Forestry Regulation Republic of Indonesia No: P.32/MENHUT-II/2009, concerning Procedures for Drafting a Rehabilitation Engineering Plan Forest and Watershed. No previous researchers have used parameters derived from remote sensing data. The majority of researchers only use geospatial data obtained from local agencies, *i.e.*, slope, land use, soil type, and rainfall obtained from field measurement (Driptufany, Guvil and Ramadhan 2019; Ristianingrum 2019; Hapsari, Nurlina and Sota 2013). Manually delineated land use takes a relatively long time, especially in large areas. Measurement of field rainfall is the same constraint. So, remote sensing data provides an opportunity for researchers to observe the phenomenon of water infiltration in the field quickly and in real-time.

The remote sensing data used was derived from Sentinel 2 Imagery. To analyze the vegetation density using the Normalized Difference Vegetation Index (NDVI) algorithm and the Bare Soil Index (BSI). Sentinel-2 is European optical imaging that was launched on June 23, 2015. Sentinel-2 was the first satellite to be launched as part of the European Space Agency (ESA) program Copernicus. Sentinel-2 consists of two constellation satellites, Sentinel-2A and Sentinel-2B, which orbit the poles in a sun-synchronous orbit at 786 km. The two identical satellites are 180 degrees apart from each other. The satellite is a medium resolution satellite with a temporal resolution of 10 days for one satellite or five days with two satellites. The spatial resolution of 10 m is four bands (B2, B3, B4, B8), 20 m is six bands (B5, B6, B7, B8A, B11, B12), and 60 m is three bands (B1, B9, B10). This satellite carries a variety of high-resolution multispectral imagers with 13 spectral bands. Researchers in various parts of the world (Luo and Wu 2022; Lasaponara, Tucci and Ghermandi 2018; Grabska *et al.* 2019; Segarra *et al.* 2020; Lu *et al.* 2021; Tavus *et al.* 2020) have used satellite image data to monitor burn area, forest land changes, floods, landslides, and agricultural land resources.

Annual rainfall was analyzed using weather satellite data, namely Rainfall Estimates from Rain Gauge and Satellite Observations (CHIRPS). CHIRPS is the product of the collaboration of scientists at the USGS Earth Resources Observation and Science (EROS) Center to provide a complete and up-to-date data set for several early warning purposes, such as trend analysis and seasonal drought monitoring. New satellite observation resources such as satellite-based rainfall from NASA and NOAA have been leveraged to build high-resolution (0.05°) rainfall climatology. When applied to satellite-based rainfall fields, this improved climatology can eliminate the major engineering systematic biases in producing the CHIRPS dataset from 1981 to the present (Bamweyana, Musinguzi and Kayondo 2021). Furthermore, researchers used elevation data derived from Alos Palsar Imagery. Alos Palsar has provided terrain correction data, known as the Digital Terrain Model (DTM), which is ready to be used for slope analysis. The spatial resolution of the elevation product from Alos Palsar is 12.5 m.

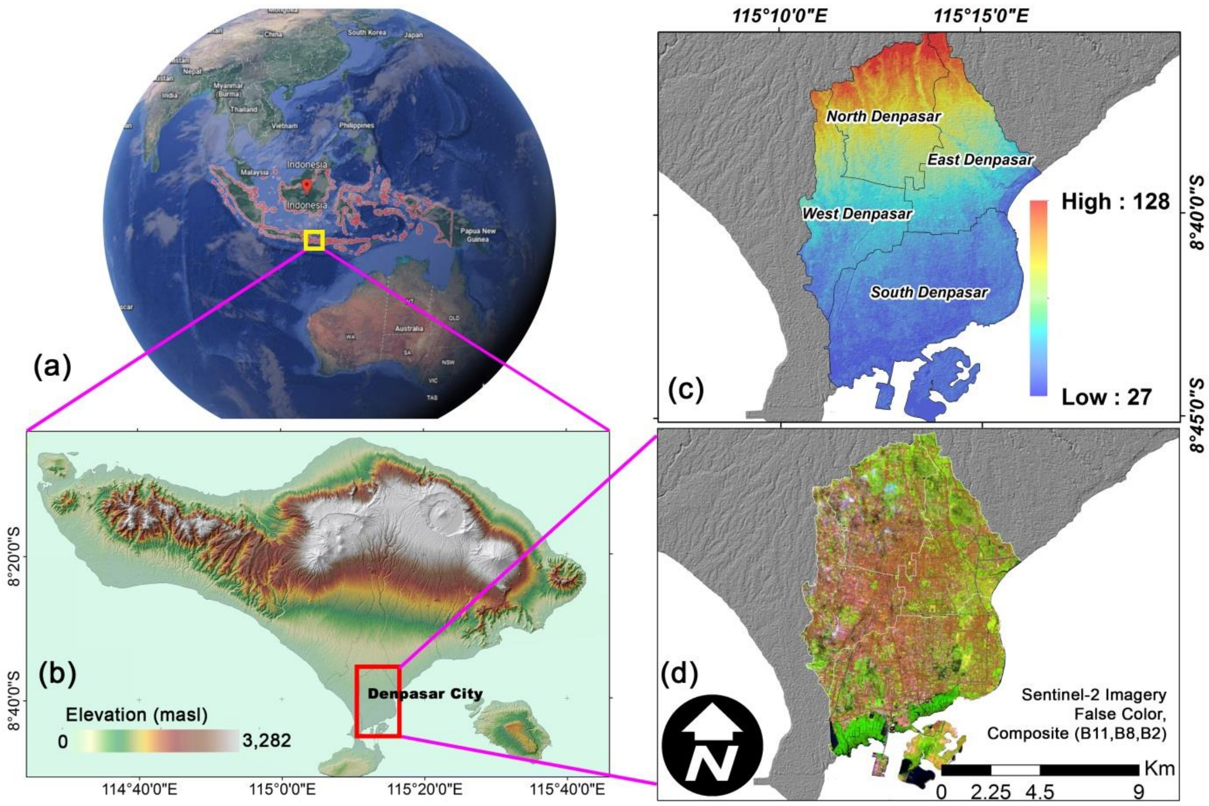
The soil texture in this study was derived from field soil samples and laboratory analysis. Then the data is converted into geospatial data through a GIS application. The reason the researcher does not use global soil grid data (https://www.isric.org/explore/soilgrids) is that the spatial resolution of the data is low. So that the application in local and urban areas is not appropriate, especially in this study. This study aims to analyze the factors that affect the potential for water infiltration, the spatial distribution of potential water infiltration, and its relationship to flood events and land cover conditions in urban areas.

1. Methodology

1.1 Region Overview

Viewed from a global scale, the research location is in Southeast Asia, the State of Indonesia (Figure 1a). Regarded from the regional scale, it is located in the Province of Bali, in the urban area of Denpasar (the capital of the Province of Bali). The case study of this research was carried out in the southern coastal region of Bali Province, with the shape of the area being flat to sloping (Figure 1b). The altitude of a special place in urban areas with a 27 to 128 msl threshold. The data derived from Alos Palsar's Digital Elevation Model (DEM) with a spatial resolution of 12.5 m (Figure 1c). It can be seen in Sentinel-2 Image (Composite B11, B8, and B2) that Denpasar City is dominated by built-up land (brown colour). From the urban center spread to the south and west. The northern and eastern parts of the area still have green zones, which indicate vegetated land covers such as agricultural land and urban green open spaces. The western region is almost covered by built-up land. The southern part of the coastal area appears to be found with high-density vegetation, the land use in the area is mangrove forest. Mangrove plants are associated with water, so some forest areas are dark in colour (Figure 1d). Denpasar City has an area of 127.78 km2 (2.27 %) of the total area of Bali Province. Administratively, Denpasar City consists of 4 sub-districts. Of the four sub-districts based on location, South Denpasar District has the largest area of 49.99 km^2. North Denpasar has an area of 31.12 km^2, and West Denpasar has an area of 24.13 km^2. The sub-district with the smallest area is East Denpasar District, 22.54 km^2.

Figure 1. Research locations on a global (a), regional (b) scale, urban area elevation map (c), and Sentinel-2 Imagery with B8, B11, and B2 Composites (d)



1.2 Tools and Materials

The materials used in this research include Satellite Imagery Sentinel -2, the average recording from May to October 2021, with cloud cover <10%. The image is for NDVI and BSI analysis. The following material is the

Digital Elevation Model (DEM) product of Alos Palsar, for slope analysis. Air-dried soil samples and chemicals Hydrogen peroxide (H_2O_2) with a concentration of 30%, and. 0.2 N sodium pyrophosphate ($Na_2PO_4O_7$) for soil texture analysis using the pipette method. Rainfall data was extracted from the CHIRPS Satellite.

The tools used for the above data analysis include Google Earth Engine (GEE), which is an online application for remote sensing data acquisition, research, and visualization (Gorelick *et al.* 2017; Tamiminia, *et al.* 2020)

ArcGIS 10.8 application we use for correlation test (pixel value extraction) and maps layout in this scientific paper. Other supporting tools such as the Global Positioning System (GPS), which is used for soil sampling in the field.

1.3 Data Analysis

Data analysis was carried out by quantifying the Sentinel 2 remote sensing data. Quantification of the vegetation index was by using the Near Infrared (B8) channel with a wavelength of 0.842 m, and Red (B4) with a wavelength of 0.665 m. In general, the NDVI threshold value ranges from -1 to 1. High vegetation density values are close to 1, while non-vegetation values approach -1 (Eq. 1.1)

$$NDVI=(NIR - Red) / (NIR + Red) \quad 1.1$$

Bare soil index (BSI) is an index that is sensitive to detecting vacant land and built-up land in urban areas. BSI quantification utilizes the Green channel band (B3) with a wavelength of 0.560 m. As well as the Near Infrared channel band, which is the same used in the NDVI calculation in the previous explanation. The calculation of the BSI value is presented in Formula 2. Annual rainfall is extracted from daily CHIRPS data, then summed into annual data, and averaged into 10-year rainfall data (years 2011-2021).

$$BSI=(Green + NIR)/(Green - NIR) \quad 1.2$$

The data was then reclassified using the Natural Breaks Jenks method (Jha *et al.* 2007; Chen *et al.* 2013; Febrianto, Fariza and Hasim 2016) and given a score based on Table 1. The parameter that has a high level of influence on the potential for urban water absorption has a score of 5, while the most inhibiting the infiltration process has a score of 1 The thematic maps were further analyzed using the weighted overlay method by giving the weights in Table 1. The scores and weights are a modification of the previous study (Wibowo 2006; Ristianingrum 2019; Hapsari, Nurlina and Sota 2013; Domínguez-Pérez and Mercado-Fernández 2020; Wicaksono, Prasetyo and Bashi 2019) by adjusting the characteristics of the area in the Denpasar urban area.

Determination of the threshold classification for water absorption potential also uses the Natural Breaks Jenks method. Classification values ranged from 1.35 to 4.20. Low values indicate critical water infiltration conditions, high values indicate good infiltration. The color symbols on the map and the threshold values for water infiltration classification are presented in Table 2.

The correlation test between the potential for water infiltration, with data on urban flood events is presented in Eq. 1.3. And uses the Root Mean Square Error (RMSE) in Eq. 1.4.

$$r=\frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \quad 1.3$$

where: r is the correlation coefficient, x is values of the x-variable in a sample, $\bar{x}$ is mean of the values of the x-variable, y is values of the y-variable in a sample and $\bar{y}$ is mean of the values of the y-variable.

$$RMSE=\sqrt{\frac{\sum_{i=1}^{N}\|y(i)-\hat{y}(i)\|^2}{N}}, \quad 1.4$$

where: N is the number of data points, y (i) is the i measurement, and $\hat{y}(i)$ is its corresponding prediction.

Table 1. Criteria and Parameters for scoring and weighting of water absorption potential

No	Parameters	Score	Weight
Bare Soil Index (BSI)			
1	0.14-0.50	5	0.30
2	0.011-0.14	4	
3	-0.14-0.011	3	

No	Parameters	Score	Weight
4	-0.36- (-0.14)	2	
5	-0.69- (-0.36)	1	
Normalized Difference Vegetation Index (NDVI)			
1	-0.75 – (-0.29)	5	
2	-0.29 – 0.23	4	
3	0.23 – 0.39	3	0.20
4	0.39 – 0.62	2	
5	0.62 – 0.93	1	
Slope (%)			
1	>30 %	1	
2	15 - 30 %	2	
3	8 - 15 %	3	0.15
4	3 - 8 %	4	
5	0 - 3 %	5	
Soil Texture			
1	Clay, Silty Clay	5	
2	Clay Loam, Silty Clay Loam, Loam	4	0.20
3	Silty, Silty Loam	3	
Rainfall (mm/yr.)			
1	>3000	5	
2	2500-3000	4	
3	2000-2500	3	0.15
4	1000-2000	2	
5	<1000	1	

Table 2. Threshold values and symbols for potential water infiltration criteria

Symbol	Range	Criteria
	1.35 - 1.92	Very Critical
	19.93 - 2.49	Bit Critical
	2.50 - 3.00	Starting to Get Critical
	3.1 - 3.62	Natural Normal
	3.63 - 4.20	Good

2. Result and Discussion

2.1 Satellite Imagery and Geospatial Data

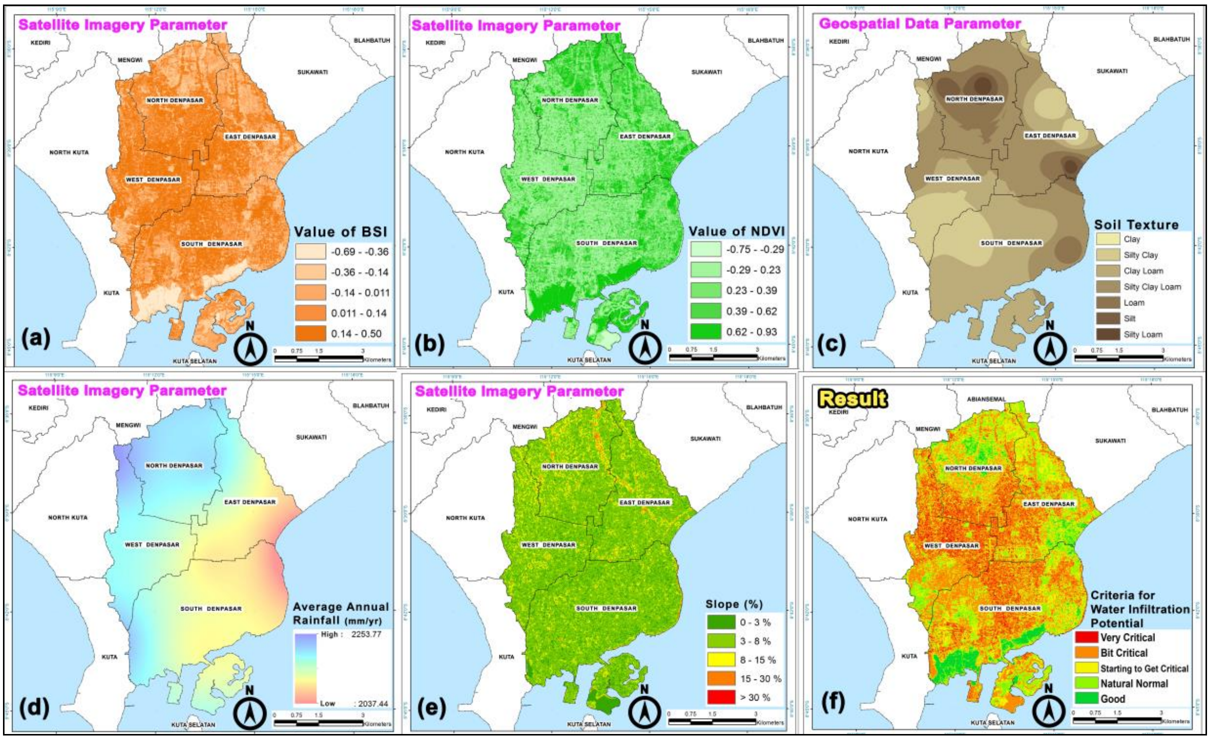
Utilization of remote sensing satellite image data in this study because the data is easy to acquire, time series, update, and available multi-resolution and multi-spectral (Chen *et al.* 2022). Utilization of remote sensing data to extract the Bare Soil Index (BSI) pixel value, Normalized Difference Vegetation Index (NDVI) derived from Sentinel 2-A Image with a spatial resolution of 10 m (Rouibah and Belabbas 2020). BSI and NDVI represent land cover conditions in the Denpasar urban area. The vegetation index is susceptible in detecting vegetation density, such as mangrove forests, mixed gardens, urban green open spaces with a high level of vegetation density, and paddy fields, fields, and meadows with medium vegetation density. The bare land index (BSI) can sensitively detect both built-up and bare land. Another use of remote sensing data is rainfall from CHIRPS with a spatial resolution of 0.05 degrees and daily temporal resolution (Climate Hazards Center. (2020). *CHIRPS: Rainfall Estimates from Rain Gauge and Satellite Observations).* Elevation data derived from the Alos Palsar imagery, which has undergone terrain correction to instantly extract the product into a slope map. Soil texture is a type of geospatial data. The data obtained through field observations with Global Positioning System (GPS) and then interpolated on the ArcGIS 10.8 application to get the spatial distribution of the entire city of Denpasar. Data from remote sensing and geospatial analysis presented in Table 3 and Figure 1.

Table 3. Statistical value of urban water absorption potential parameters

No	Parameters	Area (ha)	Area (%)
Bare Soil Index (BSI)			
1	0.14-0.50	3,764.62	30
2	0.011-0.14	3,725.37	29.69
3	-0.14-0.011	2,908.68	23.18

No	Parameters	Area (ha)	Area (%)
4	-0.36- (-0.14)	1,715.72	13.67
5	-0.69 – (-0.36)	433.43	3.45
Normalized Difference Vegetation Index (NDVI)			
1	-0.75 – (-0.29)	108.56	0.87
2	-0.29 – 0.23	3,912.41	31.18
3	0.23 – 0.39	3,320.78	26.46
4	0.39 – 0.62	2,830.45	22.56
5	0.62 – 0.93	2,375.64	18.93
Slope (%)			
1	>30 %	1.99	0.02
2	15 - 30 %	125.09	1
3	8 - 15 %	1,249.05	9.95
4	3 - 8 %	8,351.30	66.56
5	0 - 3 %	2,820.40	22.48
Soil Texture			
1	Clay	1,662.73	13.25
2	Silty Clay	2,537.77	20.22
3	Clay Loam	2,905.63	23.16
4	Silty Clay Loam	2,308.20	18.4
5	Loam	2,054.32	16.37
Rainfall (mm/yr.)			
1	2,037 – 2,253	12,547.83	100

Figure 2. Spatial distribution map of Bare Soil Index (a), Normalized Difference Vegetation Index (b), Soil Texture (c), Annual Rainfall (d), Slope (e) and Water Infiltration Potential (f)



BSI represents bare land and settlement/ built-up area; because the two types of land cover have similar reflectance values. The higher the BSI value (0.14 - 0.50) indicates the densely built-up area. Meanwhile, the lower the BSI threshold value (-0.69 - (-0.36) represents land cover in the form of high-density vegetation, namely mangrove forest. NDVI represents the level of vegetation density. The higher the vegetation index value (0.62-0.93) indicates the level of vegetation density and the level of the greenness of the leaves on plants is high. Denpasar City dominated by slopes (3-8%) with an area of 66.56% of the total area. The red color is spatially located along the river commensurate with the East Denpasar District and North Denpasar, which shows the highest level of slope (>30%). The slope above 30% has the smallest area of 1.99 ha (0.02%). Denpasar City dominated by Clay Loam soil texture, covering an area of 23.16% of the total area of Denpasar City. The coarser the soil texture, the higher the ability of the soil to absorb water Rainfall (mm/month) in Denpasar City decreases from April to September and October tends to experience a return hike. The rainfall threshold is 2,037 – 2,253 (mm/yr.), the highest in the North Denpasar area. The lowest in Denpasar, East, and South coastal areas. The spatial pattern of rainfall shows that the coastal part of East and North Denpasar District is low with a red zone. The central part of Denpasar City with moderate rainfall (yellow area), and the western part of Denpasar City (border with Badung Regency) has high rainfall (blue).

The parameters of remote sensing satellite image data and geospatial data have different effects on the potential for water infiltration. Each type of soil has a different effect depending on the characteristics/properties of the soil. One of the soil properties that affect water infiltration is soil texture. Coarse textured soils such as sand or sandy loam have a higher infiltration rate than clay textured soils because the space between soil particles (macrospores) in sandy soils is more. Sandy soil texture is usually found in areas with intensive sedimentation processes. Clay has a fine texture and retains water, so the infiltration rate is very slow compared to sand-textured soil. The water movement in the soil is an essential aspect of agriculture. Several essential processes, such as the entry of water into the soil, the movement of water into the root zone, the release of excess water or drainage, runoff, and evaporation, are strongly influenced by the ability of the soil to pass water.

Changes in land use in the emergence of new settlements and other types of land use that can reduce infiltration rates need to be considered (Ren *et al.* 2020). Widespread land use with low infiltration rates will bring problems, especially in the form of disruption of the water balance in an area. Present land use is a sign of the dynamics of exploitation by humans, both individually and in society, of a set of natural resources to meet their needs. Land use that does not follow its designation will allow land degradation and eventually become critical land (Fung *et al.* 2022). Hydrologically critical land is characterized by a large ratio between the maximum discharge (rainy season) and minimum discharge (dry season) and excessive mud content. The slope shows the magnitude of the slope angle in percent or degrees. The slope of slope plays a role in determining the proportion of water that becomes runoff and water that experiences infiltration. The steepness, the slope's length, and the slope's shape (convex or concave) all affect runoff. The position of the slopes in an area affects the amount of rain and the amount of water received. The runoff has a high velocity on land with steep slopes, so the water lacks time for infiltration (Morbidelli, *et al.* 2018; Rahardjo 2020; Hou *et al.* 2019). As a result, most of the rainwater becomes surface runoff. On the other hand, on flat land, the water stagnates to have enough time for infiltration. The position of the slopes in an area affects the amount of rain and the amount of water received. Areas located at the bottom may have a lower catchment than the surrounding area.

Rain is an event that drops water droplets from the sky to the earth's surface due to condensation. The amount and duration of rainfall intensity affect the amount of water infiltration in the soil, influenced by land use, slope, and soil type (Morbidelli, *et al.* 2018; Rahardjo 2020; Hou *et al.* 2019). The amount of precipitation recorded in inches or millimeters. The amount of rainfall of 1 mm indicates the height of rainwater that covers a flat earth surface of 1 m^2 if the water does not seep into the ground or evaporate into the atmosphere. Rain affects infiltration capacity in various ways. Intensity and duration are essential rainfall factors in their effect on infiltration. The surface runoff will occur if the rainfall intensity exceeds the infiltration capacity. There are sequential processes in the groundwater absorption process: infiltration and percolation (Assouline 2013; Morbidelli *et al.* 2019). Infiltration is the water movement from above into the soil surface, while percolation is the downward movement of water from the unsaturated zone to the saturated zone. In the hydrological cycle, the infiltration process is essential because it affects the amount of water on the soil surface. Infiltration occurs when rainwater falls on the dry soil surface, which will cause the soil surface to become wet while the bottom is relatively dry, resulting in capillary forces (Morbidelli *et al.* 2018, Assouline 2013). If the infiltration is larger and the rainfall is smaller, then the subsurface runoff will be small, and vice versa; if the infiltration is smaller and the rain is larger, then the runoff will be large. The runoff occurs depending on the conditions and properties of the soil in an area.

2.2 Spatial Distribution Map of Water Infiltration and Relationship with Flood Events

Denpasar City has the potential for water infiltration and is good in very critical conditions. West Denpasar District is the largest area with very critical water infiltration potential (382.41 ha). The largest area with somewhat critical water catchment potential is located in South Denpasar (1,900.28 ha). In critical conditions, the widest potential for water infiltration is found in South Denpasar District (1,479.68 ha). South Denpasar District has the largest natural water infiltration potential (766.55 ha). The water infiltration conditions in the good category are found in South Denpasar (455.67 ha). The area of Denpasar City's water infiltration potential is presented in Fig. 2f and

Fig. 3. The red zone indicates critical water infiltration conditions, while the green indicates good water infiltration conditions. The central part of the Denpasar district (city center) shows a red zone, then spreads outwards to the orange city of Denpasar, then turns yellow, and in coastal areas and borders with Badung Regency (west) and Gianyar Regency (east) shows the dominance of green.

Good water infiltration conditions are found in areas with better actual infiltration area conditions or greater infiltration capacity than potential infiltration conditions, such as in areas with land use in the form of forests that have large existing catchment areas. This critical water infiltration condition generally occurs because it is located on built-up land and settlements, which are low in passing water. The actual conditions influence this condition in Denpasar City, which has a small infiltration capacity due to the dominance of land use in the form of settlements so that it is two levels lower than its potential condition, which is dominated by moderate infiltration potential (Fig. 4).

Figure 3. Graph of comparison area with the condition the potential water infiltration

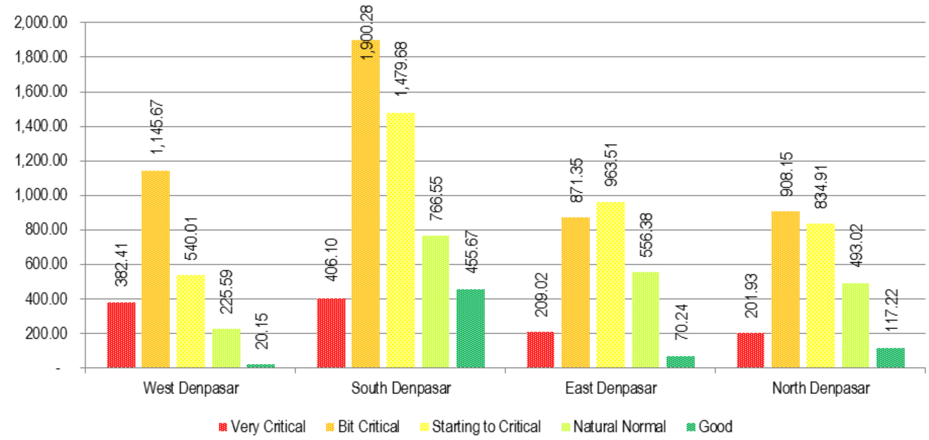
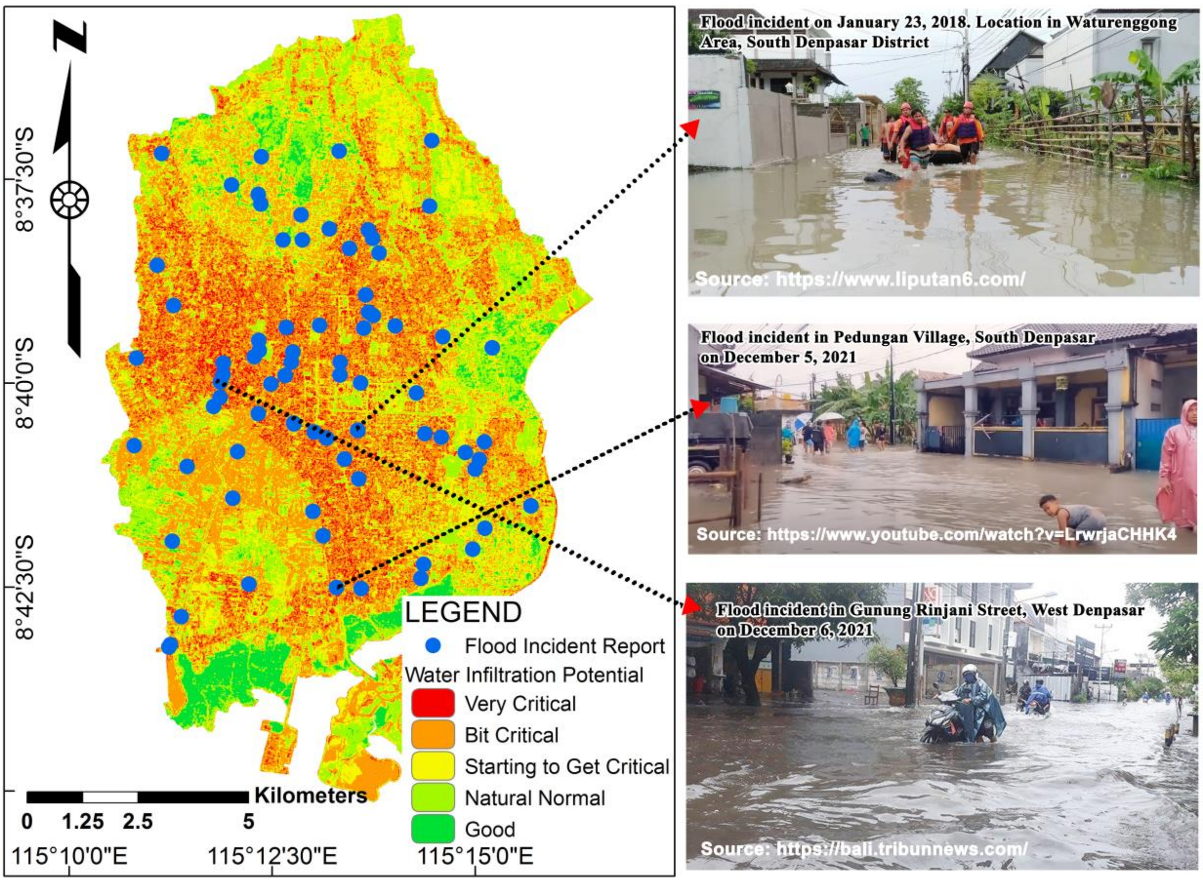
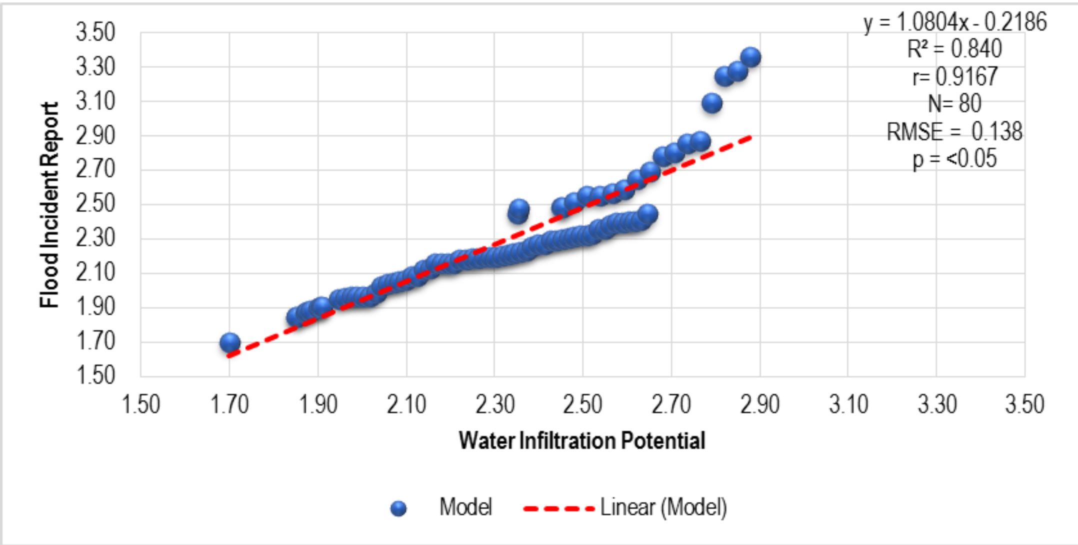


Figure 4. Relationship between the spatial distribution of water infiltration and the point of occurrence of flooding in urban areas



The corelation of the water infiltration map was carried out by comparing flood events in Denpasar City, which came from reports from the mass media, reports from regional disaster management agencies, and interviews with local residents. The researcher believes that very critical water infiltration conditions cause the frequent occurrence of floods in urban areas. So that the validation of flood events is very relevant to be carried out in this study. The corelation results show (R^2 = 0.84), (r = 0.916), Root Mean Square Error (RMSE = 0.138), and *p-value* <0.05, these values indicate very high relation (Figure 5). There is a strong relationship between urban water infiltration conditions and the incidence of flooding. The condition of water infiltration affects the occurrence of floods in Denpasar City. Flood events often occur in zones with very critical water infiltration with high building density and low vegetated land cover. One such condition occurred in the Districts of West Denpasar and South Denpasar.

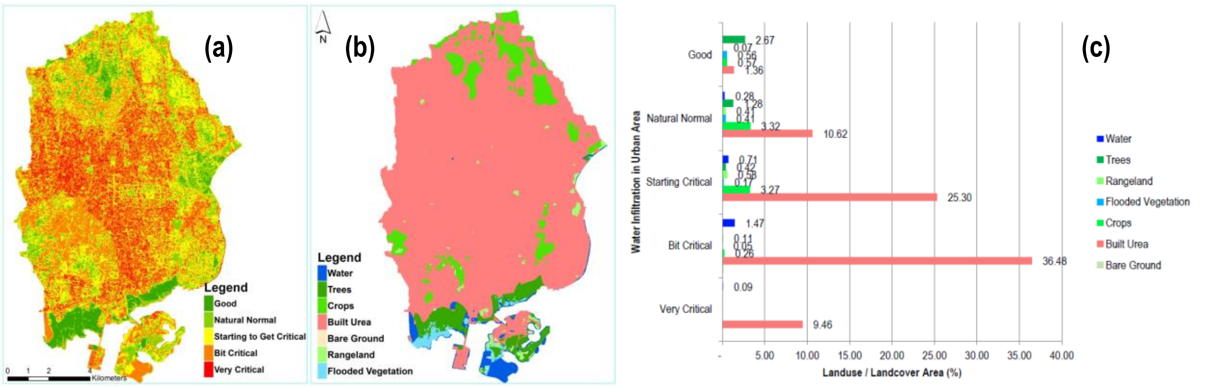
Figure 5. Linear regression graph between water infiltration and flood events. The higher value near the x-y axis, indicates the area is safe. Has good water infiltration potential, and there are no flooding events



2.3 Relation Water Infiltration with Landuse/ Land Cover (LULC)

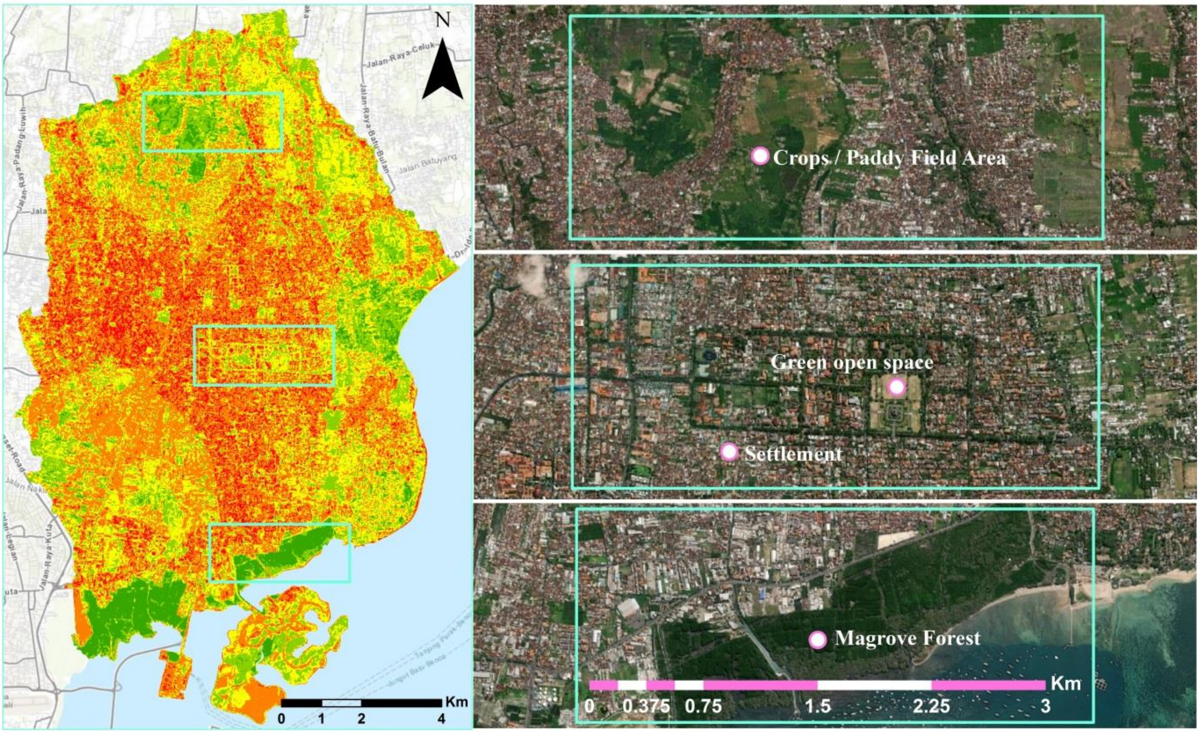
Comparison between the potential for water infiltration with the LULC map of Denpasar City in 2021 (Figure 6a,b). LULC is produced from Citra Sentinel-2 through the deep learning method (Karra *et al.* 2021) Researchers want to know each condition of water infiltration with the proportion of existing land use. In general, good water absorption potential is in the proportion of vegetated land use (trees, crops, and rangeland) with balanced built-up land. In the natural normal and starting critical categories, built-up land begins to dominate, but there is still a relatively high percentage of vegetated land. Bit critical category, vegetated land is only less than 1%, and built-up land reaches 37%. The condition is very critical, only being built without any vegetated land (Figure 6c).

Figure 6. Spatial distribution of water infiltration (a), LULC in 2021 derived from Esri Land Cover 10 m (from Sentinel 2-A) free acces by https://www.arcgis.com (b) , and graph of water infitration and LULC coverege (c).



The spatial pattern of water infiltration potential is more visible in more detail by comparing it with High-Resolution Satellite Imagery. For example, the potential for good and natural water infiltration is normal on vegetated land, namely rice fields and other plants. They are spatially located in the northernmost part. The urban center section shows a green open space named Niti Mandala Renon. The pattern of urban green space appears to surround the central office area, with normal, natural water absorption conditions. The southern coastal area shows a very high vegetation density. The potential for water infiltration in the region is a good category. It can be seen on the satellite image that the boundary between densely populated settlements and high-density vegetation land, with the use of mangrove forest land (Fig. 7).

Figure 7. Comparison of water infiltration potential (left) with natural colors in High Resolution Image (riht) using Esri World Imagerry Basemap



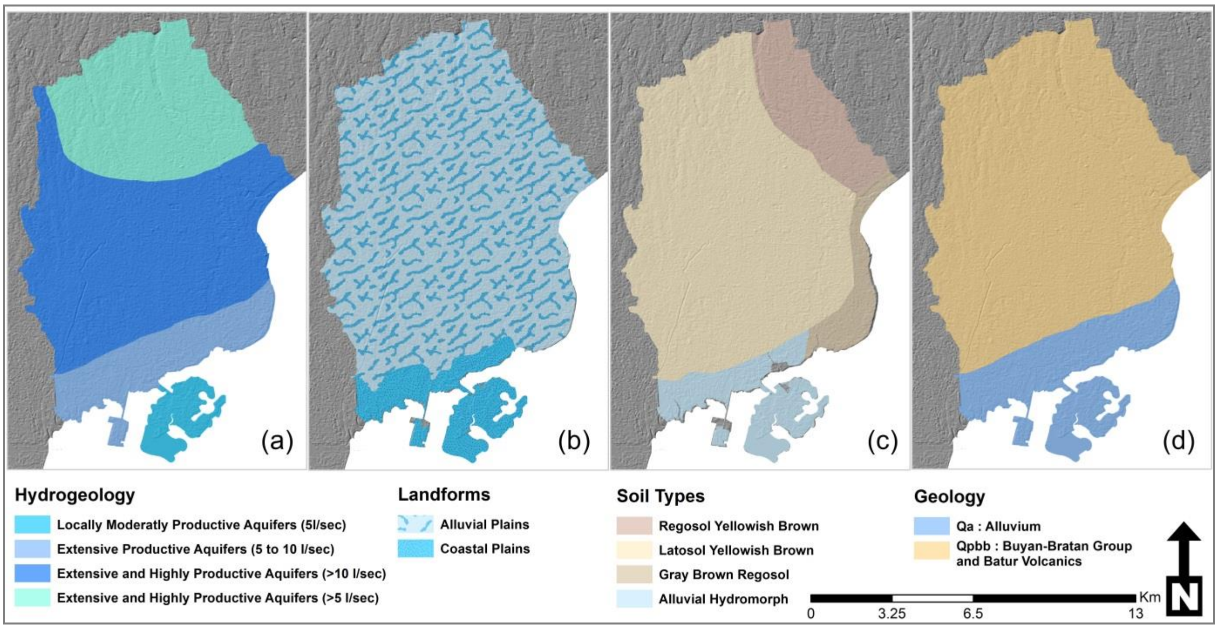
The weakness/ uncertainty of this research is the limited use of the vegetation index and vacant land. The index is weak in detecting wetland areas such as rice fields and mangrove forests. Near-Infrared and Red channel bands are the most appropriate for detecting the surface of vegetated land and built-up land. Alternatively, it is recommended to use a water-sensitive index transformation such as the Normalized Difference Water Index (NDWI), a moisture index such as the Normalized Difference Moisture Index (NDMI), and the Soil Moisture Index (SMI). It is necessary to transform elevation data related to an area's wetness level, such as the Topographic Wetness Index (TWI). The resulting water infiltration potential map represents the general condition of vegetation density, which is captured by passive sensors from outer space by Sentinel 2 Image (Saha and Agrawal 2020; Ticehurst, Teng and Sengupta 2022; Zhu *et al.* 2011). Extracting all indexes on the parameters cannot yet represent plants associated with water so that the potential for water infiltration in the area is considered natural, normal, and good. In areas associated with stagnant water (wetlands), it should indicate critical water responsiveness. Because the area is flooded, the soil pores are filled with water (saturated condition), so they are unable to absorb water in the soil (impeded infiltration process). Other researchers (Halder and Bandyopadhyay 2022; Kaplan and Avdan 2018; Ghorbanian *et al.* 2022) recommend using satellite data with active sensors, such as Satellite Aperture Radar (SAR), with high sensitivity capabilities in areas associated with water. The types of parameters and indices used in this study are very suitable in urban areas without any wetland areas (rice fields and mangrove forests).

3. Researcher Comprehensive Overview

The study would like to convey that the findings only discuss the potential for infiltration in shallow soil layers (surface only). Therefore, that it discusses the role of land cover on the soil surface on the infiltration rate. Elements of geology, geomorphology, and soil types were not used in the data analysis. The researcher believes that the geology and geomorphology available in the research area are suitable if it implemented on regional or provincial scale research in Bali. So that it is clear that, the boundaries of the differences in each hydrogeological parameter, soil type, and others are visible. The thematic map can be seen in Fig. 2, with data sources from more than 20 years ago with a small scale of 1:250,000.

In terms of available hydrogeology, urban areas have abundant groundwater potential. Category of an aquifer with moderate to high productivity with good discharge >5 to >10 Lt/sec. Alluvium lithology of coastal deposits, composed mainly of sand, is generally of high grade. The other part of the area comprises lithology from young volcanic products consisting of volcanic breccia, sandy tuff with lahar deposits, mainly composed of loose sand-sized material to local chunks of lava. This condition causes the permeability in Denpasar city to be relatively moderate to high. The southern coast has alluvial geology consisting of Cobble, pebble, sand, silt, and clay as river lakes and coastal deposits. The central and northern regions are composed of the Buyan-Bratan Group and Batur Volcanics geological formations. Landforms of the southern coastal area, namely coastal plains and others, a dominated by alluvial plains. From these parameters, Denpasar City has no problems regarding the potential for infiltration into the soil. And so far, there has never been a scarcity of groundwater in the urban area of Denpasar. However, there is a relationship between the spatial patterns of infiltration found in this study in terms of soil type. The dominant soil type is yellowish-brown latosol. The soil has a higher clay and clay fractions composition, so its ability to pass water is relatively low.

Figure 8. Thematic map in Denpasar city ie., Hidrogeologycal map (a), Landforms (b), Soil Types (c) and Geologycal Map (d)



Source :- Hidrogeological map in 1986 Scale 1:250,000 (By Directorat Geological and Mining Area Environmental)
- Map of Soil Types in 1970 Scale 1:250,000 (Results of Mapping Sukirno, Murdani and Pangudijanto in 1957)
- Landforms map derived from ArcGIS Rest Service acces on 2021 (Ministry of Environment and Forestry)
- Geological map in 1998 Scael 1:250,000 (By M.M Purbo-Hadiwidjojo, H. Samodra and T.C Amin)

Water infiltration areas are characterized by several main elements, including the ability of the soil to absorb high water, significant differences in groundwater, and the soil covered by cover vegetation with a fairly deep root system. There are various water infiltration areas, such as green open spaces or artificial water catchments in technology such as biopore.The infiltration area can be increased and supplemented by selecting suitable vegetation for planting. Improve soil conditions to make it easier to absorb water. Another action is producing biopore holes/infiltration wells to increase the amount of water infiltration in big cities and the addition of green open spaces such as city parks. In addition, it can also do it by making infiltration wells and keeping the water catchment area from being converted into buildings that are not environmentally friendly. Addition of organic matter to every agricultural land, yard plants, and land planted with trees in various urban spaces. Organic matter can bind clay particles in the soil to make meso pore space available and facilitate the infiltration process into the soil. The most important thing is that it is necessary to maintain urban green open spaces, reforestation at the household scale, and streng then regulations on controlling land-use change.

Conclusion

The main problem in densely populated urban areas located in coastal areas is hydrological disasters such as floods. The disturbed infiltration process causes this due to compact and dense soil conditions due to high building loads. This study reveals the phenomenon of frequent flooding in urban areas through a spatial analysis of the potential for water infiltration. The use of satellite image data with remote sensing techniques and geospatial data with GIS techniques can streamline the spatial analysis process. Coastal urban areas tend to have the same hydrogeological conditions, soil types, geology, landforms, and physiography. Land cover in urban areas tends to be dominated by settlements, so researchers use the Bare Soil Index (BSI), which is sensitive to detecting built-up land and vacant land. To develop a water infiltration potential map, it is necessary to combine other parameters such as the Normalized Difference Vegetation Index (NDVI) derived from Sentinel Image -2 (10 m) and Slope (Alos Palsar 12.5 m). Annual Rainfall from CHIRPS 0.05°, and soil texture through laboratory analysis.

Denpasar City has the potential for water infiltration and is good to very critical conditions. West Denpasar District is the largest area with critical water infiltration potential (382.41 ha). The largest area with somewhat critical water catchment potential is located in South Denpasar (1,900.28 ha). In critical conditions, the widest potential for water infiltration is found in South Denpasar District (1,479.68 ha). South Denpasar District has the largest natural water infiltration potential (766.55 ha). The water infiltration conditions in the good category are found in South Denpasar (455.67 ha). The correlation of the water infiltration map was carried out by comparing flood events in Denpasar City. The correlation results show (R^2 = 0.84), (r = 0.916), Root Mean Square Error (RMSE = 0.138), and *p-value* <0.05, these values indicate very high relation. Flood events often occur in zones with very critical water infiltration with high building density and low vegetated land cover. One such condition occurred in the Districts of West Denpasar and South Denpasar. Good water infiltration potential is in the proportion of vegetated land use (trees, crops, and rangeland) with balanced built-up land. In the natural normal and starting critical categories, built-up land begins to dominate, but there is still a relatively high percentage of vegetated land. Bit critical category, vegetated land is only less than 1%, and built-up land reaches 37%. Overall, urban areas have water infiltration conditions of moderately critical to very critical. This condition is necessary to get serious management so as not to cause an increase in the level of criticality in other areas. This condition needs to be watched out for and encouraged by land use management and regulations by the Government to control land conversion into buildings.

Acknowledgements

Acknowledgments are conveyed to the Chairperson of the Research Institute for the Community of Udayana University for the Grant Fund Number: B/96-228/UN.14.4A/PT.01.05/2021.

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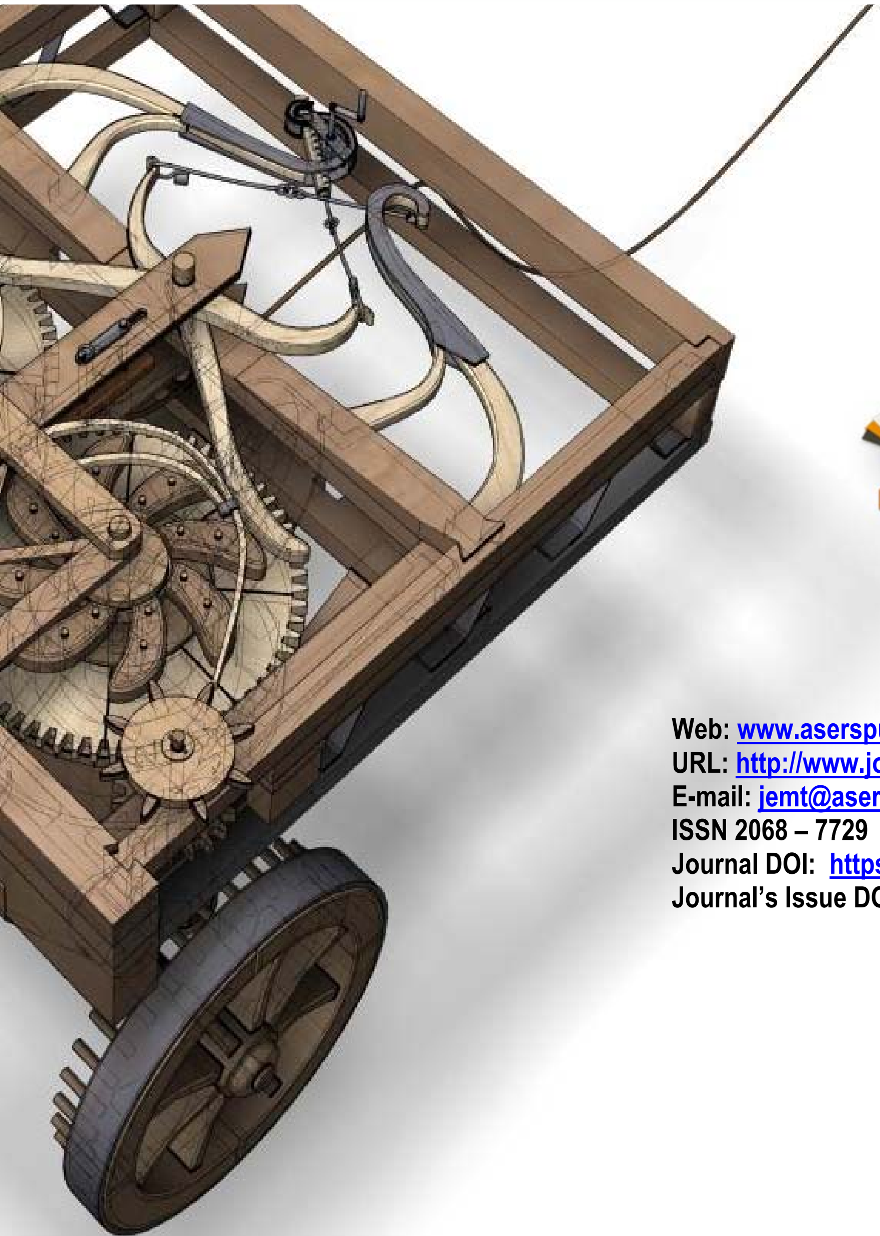

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