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Effects of Poor Drainage Towards Road Functionality

Efek Drainase Buruk terhadap Fungsional Jalan

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ABSTRACT

Batam City with existing drainage issues is a major hindrance to its performance. Road construction is always related to drainage funcitionality. The existing condition, with heavily piled-up sediments, causes a significant issue for Batam, Nagoya, and Batam Kota sub–district. Sediment accumulation in the drainage base depth causes a reduction in drainage volume, resulting in backflow and disturbance of water flow dynamics. This slowly erupts to the surface and cause flooding in roadways. Flooding roadways cause traffic congestion, erosion of the road structure, and accumulation of sediments due to the intensity of rainfall. Which resulting damages to drainage system. By installing sediment traps on manholes and lower base drainage, it can help reduce the buildup of sediments on the drainage base. Which will reduce flood risk and allow water to flow smoothly without resulting in backflow.

1. Introduction

An inadequate drainage system has posed significant challenges for citizens, transportation and road accessibility. A well - functioning drainage infrastructure is a critical component when planning and constructing road structure [1]. Not only manages wastewater and ensures environmental sanitation but also protects road pavements, structures, and streets from flooding, soil erosion, and the formation of potholes [2]. Inadequate or existing drainage conditions can result domino effects such as disrupting traffic flow and accidents can result in flooded streets and obscured lanes. Therefore, it is crucial for the government to prioritize the use of suitable materials for drainage systems and to conduct thorough soil evaluations before embarking on road construction projects.

Transportation has evolved significantly, from developing of vehicles that creates road networks. There is a significant correlation between population growth and high vehicle demand. With existing urban drainage, it is giving high stress beyond the design. Excessive land use is not balanced with an adequate drainage system due to population growth and high Transportation. With an imbalance in drainage capacity and road expansion to support high-density transportation, it puts both sides at high risk when heavy rainfall comes [3]. However, countries like Indonesia still experiencing traffic congestion due to road capacity unable to withstand high volume of vehicles. Despite the government's substantial efforts to improve road conditions, persistent challenges such as inefficient drainage systems often render roads impassable due to puddles and flooding [4]. This water accumulation not only obscures the surface pavement but also contributes to the deterioration

of road quality by creating potholes. The combination of poor drainage and heavy traffic density exacerbates congestion, further accelerating road damage [5].

The impact will be critical as for Indonesian cities that always increasing number of vehicles (Vendhy et al., 2022). Vehicles operate daily for various activities, leading to high stress on both upper and lower road structures. With the additional high supply of vehicles to Indonesia, these two main factors are triggers for several other issues, such as cracks or potholes and road expansions. Urban areas are typically crowded with pedestrians, cars, motorcycles, and container trucks. However, the drainage systems provided by the government are insufficient to cope with the demands of this bustling environment. As a result, many regions lack adequate drainage due to low sediment depths, leading to an increased water level in drainage systems and surface rainwater accumulation on roads [6] Due to existing drainage conditions with piled up sediments and garbage, this results disrupting water flow, increasing water level, and rainwater that causing backflow in drainage system that will accumulate on roads [6]. This persistent flooding gradually erodes the soil beneath the concrete, undermining the integrity of the roadway. Consequently, the drainage system fails to operate effectively, causing water to continue running up to the road surface, destruction of the surroundings, and endangering human lives [7].

Many urban areas with existing drainage systems, such as Nagoya and Batam Centre, face significant damage to the people, transportations, and lower structure from accumulation water to cracks or holes to the road and additional impact from high density traffic. The rapid population growth, combined with human activities and increased traffic density in Batam city, has strained the hydrological cycle, negatively impacting urban drainage systems. As a result, rapid construction reduces the natural soil absorption of land, which can cause flooding. Existing drainage systems cannot cope with heavy rainfall, which can damage them further by rapid flood flow, bringing sediments and increasing the water level higher (Erfan S et al., 2021). Poor drainage will leads to roadways becoming submerged during rainfall, causing water to pool and form puddles. This occurs when the drains to overflow and backflow. Consequently, road surfaces deteriorate over time due to water exposure, creating hazardous conditions that can lead to accidents, injuries, and property damage [8]. Such conditions not only pose a threat to the safety of road users but also increase the likelihood of vehicle collisions, as drivers struggle to navigate the damaged roads (Isradi M et al, 2021). Despite of the effects, improvements and repairs to these systems are urgently needed.

Batam growing population is precipitating significant changes in land use, which in turn heightens the risk of flooding. This increase in flooding risk can be attributed to inadequate and poorly maintained drainage systems, as well as increasing population growth, high vehicle intake, and the massive use of land for construction or factories that eliminate natural water infiltration [9]. Such challenges can lead to a myriad of issues, including the formation of puddles, the development of potholes, and an uptick in accidents, all of which disrupt the daily lives of residents. Unfortunately, most big cities in Indonesia, the planning and design of drainage systems remain suboptimal, resulting in widespread flooding and damage to concrete roads. This is caused by existing drainage that is filled with sediments, and the drainage pipe cannot transport the water flow smoothly, resulting in backflow that causes flooding on the surface [10]. Despite its crucial importance, the existing drainage system in Batam Subdistrict Nagoya and Batam Centre is far from functioning properly. This study will use Nagoya and Batam Centre existing drainage conditions as the base sampling locations for assessing the effectiveness of the drainage system and the factors that contribute to the damage of Nagoya's existing drainage system.

2. Backgrounds

Batam City is one of the major cities in Riau Island that has experienced the biggest revolution since the 1970s. The revolution in Batam City has been quite significant in all aspects, including infrastructure, economy, transportation, and others [11]. Revolution occurs from the growth and migration of the population in Batam. Batam city is known as an industrial city that offers numerous job opportunities from outside companies operating in Batam, specifically in Batamindo Industrial Park, Panbil Industrial Estate, and Kabil Industrial Estate. And therefore, year by year, many locals move to Batam City to pursue a better career. Despite the growth of population, it triggers more revolutions in excessive land use for construction and high demand for transportation.

Figure 1. High Density traffic Location Batam Sub District

Rapid growth in Batam can cause a high volume of vehicle intake. Due to Batam being located in a strategic economic Free Trade Zone center. This can cause high stress and damage to road infrastructure. The imbalance between limited road pathways and public or private transport, with a large volume of vehicles, is catastrophic [12]. With additional existing drainage conditions, during rainfall, floods can occur easily due to the decreasing depth of drainage caused by sediments, which can lead to heavy traffic congestion, rerouting, damage to the surrounding area and vehicles, accidents, and the formation of cracks or potholes. This will result in discomfort while driving and structural failures in both the upper and lower structures of roads [13].

The evolution of Batam City and its strategically located economy has enabled many citizens and families to own private cars (Qu E et al., 2024). With a heavy load of transportation, drainage must be maintained to remove stormwater from the roadside, as it can trigger major traffic congestion. Waterlogged roads endanger drivers due to reduced visibility on road paths and decreased wheel friction resulting from the drag force of water. Tension created by water mass and traffic, as well as road deterioration, doubles the process that reduces structural integrity in a shorter period [14]. With drainage as the key vital for draining storm water, it faces critical damage over time from human activities. Human activities have led to a significant decline in drainage efficiency over time. This can lead to a further domino chain effect on road structure, soil deterioration, traffic congestion, vehicle damage, health issues, and human lives [15].

Most of Batam's sub-districts, such as Batam Kota and Lubuk Baja, have their own existing drainage systems in poor condition, with low performance in draining high-capacity volumes. With existing drainage conditions that have been degraded by human activities, there is lower drainage efficiency and

a reduced volume capacity for wastewater and stormwater. With Batam City having limited access to the city's sewer line and wastewater treatment plant, in addition to the existing drain condition, it cannot drain a large amount of untreated wastewater and stormwater in a short period, causing floods in urban areas. This can cause road access to be blocked, extreme traffic congestion, reroutes, potholes, unpleasant smells or illness, and accidents, potentially resulting in loss of human life (Navarrete H.R et al., 2022).

With Batam City facing urbanization and inter–city migration, natural land is being converted into man–made land for infrastructure. Changes for modernization to the city is caused by high population growth. High population growth can change water dynamics, flow of natural drainage, and reduce soil absorption, which can have disastrous effects on the hydrological cycle [16]. On top of that, existing drainage systems with poor systematic function cannot drain stormwater accumulation on the road surface, causing floods that decrease road functionality. Damages can be fatal not only to human lives but also to economic wise on private owned vehicles and road pathways. Water accumulation gives domino chain effects from floods on road access being blocked making it unsuitable for driving [17]. Transportation will be seriously affected on floods from existing condition. Forcing reroutes from impassable access will cause traffic congestion. Damages from water mass and heavy traffic will accelerate road deterioration, which could lower road functionality.

3. Literature Review

3.1 Existing Drainage Systems

Effective drainage is a crucial consideration prior to road construction. The drainage system is essential for urban residents, as any functional failure can lead to a chain reaction that disrupts daily life and causes significant damage to infrastructure, including roadways (Oliveira, 2022). Unfortunately, many urban areas experience flooding due to inadequate or heavily damage drainage systems. Water accumulation on roads can contribute to road erosion, which reduces their structural strength and density (Raga F.M et al., 2021). This is because drainage infrastructure plays a vital role in urban spatial planning, bridging the gap between natural requirements and the needs of the built environment. The natural water cycle necessitates a floodway for rainwater collected in the watershed, while urban areas require safe and healthy spaces for various activities and services. When urban drainage systems fail to operate effectively, they can lead to numerous problems, disrupting daily life and posing risks to citizens' safety. One of the most significant consequences of inadequate drainage is flooding, which can profoundly affect both the physical and mental well-being of those impacted. Moreover, flooding can damage infrastructure, particularly roads, leading to issues such as asphalt erosion and the gradual formation of potholes [18]. An enhanced drainage system is essential for effectively managing rainwater, sewage, and other runoff. Prior to construction, meticulous planning and design are crucial. When the drainage system malfunctions, water can pool on road surfaces, leading to significant damage. This accumulation of water, combined with the impact of traffic, increases the risk of accidents and contributes to the development of potholes, cracks, and pavement deterioration [18]. Drainage systems play a crucial role in managing water runoff from road surfaces, effectively separating the roadway from the surrounding environment. These systems are designed to direct water toward exit points, ensuring its safe disposal. A well-constructed drainage structure boasts high capacity enabling it to handle significant discharge and pressure. Subsurface drainage is particularly vital in pavement design, as it helps prevent backflow and reduces the risk of flooding in urban areas or water accumulation on road surfaces [18].

3.2 Traffic Congestions

Traffic congestion occurs when the volume of vehicles on the road exceeds its capacity, often resulting in accidents (Wincent et al., 2022). One factor that can contribute to this congestion is a poorly designed or high sediments in drainage system. Such systems may struggle to handle large volumes of water, leading to backflow that can spill onto highways. When roads become flooded, they are at risk of damage from prolonged exposure to water. Extended flooding can gradually erode the asphalt, compromising its density and strength. This deterioration not only creates potholes and increases the likelihood of road accidents but also poses significant environmental concerns [19]. Natural disaster flooding, often exacerbated by inadequate drainage, can lead to both structural failures, such as road inundation, and functional failures, like reduced travel speeds. Consequently, flooding may result in road closures and rerouting, putting drivers, especially motorcyclists, at a greater risk of accidents. Such disruptions can increase traffic on alternative routes, ultimately worsening congestion in the flooded areas. As a result, road inundation and traffic congestion can significantly contribute to indirect failures in road and transportation systems [20]. Research indicates that road inundation, which leads to traffic congestion and accidents, can be traced to several key factors, including heavy rainfall and inadequate drainage systems. When rainfall exceeds the drainage capacity, flooding occurs, trapping numerous vehicles in severe congestion and forcing rerouting as some roads become impassable. This situation not only exacerbates traffic issues but also places excessive strain on the roads, leading to gradual deterioration due to water and vehicle overload. This causes large-scale immersion of exceedingly thick built-up and street systems, potentially causing harm to human life and property [21]. Heavy, dense traffic combined with flooding can result in significant damage to roads due to the weight of vehicles and the accumulation of water. This can lead to poorly maintained roadways, creating discomfort or possibly resulting in loss of life for both drivers and motorcyclists. Consequently, the risk of accidents increases, and economic loss also occurs from damaged vehicles that are unable to drive, potentially blocking laminar flow drains to the drainage system [17].Making it essential for the public to pay close attention to these conditions. Effective solutions must be implemented to address this issue and enhance road safety.

3.3 Damages and Effects

A deficient drainage system can result in water flooding, which has an adverse impact on the sustainability of road infrastructure. This flooding may lead to a series of problems, including the formation of cracks, degradation of asphalt, an increase in accidents. When roads are subjected to flooding, their overall condition and integrity are compromised. Such water-related issues are recognized as significant threats to roadway sustainability [22]. these challenges include the development of cracks and holes, an increase in vehicle collisions, and severe congestion caused by the need to reroute traffic. Water and flooding, which lead to cracks and potholes in road surfaces, remain a significant problem. Beyond merely damaging the roads, these conditions can result in accidents, particularly as drivers may speed to navigate the hazards (Gital Y. A. et al., 2022). In a country like Indonesia, characterized by unpredictable rainy seasons and inadequate road maintenance, the risk of accidents remains high throughout the year. This situation not only results in the wear and tear of vehicle parts but also poses serious dangers to drivers. Furthermore, poor maintenance translates to subpar road performance, creating uncomfortable and often perilous driving conditions [23]. Flooding leads to severe congestion on roads by impairing accessibility and disrupting daily routines. These disturbances have a significant impact on transportation performance [24]. Areas inundated by water can diminish network capacity, escalate traffic volumes, and exacerbate congestion and accessibility issues. Moreover, accessibility challenges often trigger a domino effect, compounding existing problems due to inadequate road infrastructure and heightened congestion [25]. Therefore, it is crucial to address

traffic congestion promptly to mitigate its damaging effects on surface pavements and the surrounding environment [5]. Flooding remains a significant concern due to its cascading effects, particularly on road functionality. It not only disrupts traffic flow but also impacts production and livelihoods in various ways. Inadequate drainage systems can lead to flooding when heavy rainfall occurs, as they are unable to accommodate large volumes of water. This situation not only results in loss of life and property but also undermines the functioning of critical activities within the city [26].Therefore, it is essential to address this issue promptly and undertake necessary reconstruction efforts.

Figure 2. Existing Drainage Condtions in Batam Centre Sub – District

Figure 3. Existing Drainage Condtions in Nagoya Sub – District

4. Methods

Data is the most valuable element of conducting scientific research. Having proper element data will help the outcome of this research study. The process of obtaining the data involves identifying the location of the research issue. The areas chosen are in Nagoya and Batam Centre Sub – district. The selection of this area are based on existing conditions that face frequent floods during heavy rainfall [27]. This research can employ various research methods; hence, best practices are the most suitable for this research due to the need to obtain primary and secondary data and interpret the answers from the data. The studies related to existing drainage, floods, causes, and effects on road functionality were assessed in relation to the research [28]. To facilitate this research, supporting data on the existing drainage condition have been processed, including sediments, human activities, and external factors.

5. Result and Discussions

Figure 3 shows the location of poor drainage under existing condition. Floods can occur due to human activities, external factors, and the buildup of sedimentation. Mostly sediments are the biggest factor in decreasing drainage depth, which affects water volume intake compared to the original design [29]. Sediments that pile up in drainage channels cause disturbances in water flow dynamics. A pile-up of sediment below drainage channels is associated with the dysfunction of drainage systematic performance [30], as shown in Figure 6.

Figure 6. Sediment build on drainage channels, Batam Kota Sub – District, Source : Real Time Observation

Intense rainfall with existing drainage, lacking proper maintenance, can lead to extreme traffic congestion, blocked road access, difficulty navigating pathways, and accidents. Rainfall can cause floods in drainage channels that exceed the capacity. This can clog the main drainage channel and cause backflow that will overflow to the surface [31]. This causes a domino chain effect, forcing reroutes and blocking road access during heavy rainfall, as shown in Figure 7. These factors are the main causes of extreme traffic congestion and reduced road functionality.

Figure 7. Floods on impassable road, Location Batam Kota Sub – District, Source : Real Time Observation

Impassable roads caused by floods are mostly due to piled-up sediments that result in lower depth drainage. Sediments are transported by high velocity drainage flow. Sediments usually caused by erosion and micro particles on roads. High-intensity rainfall can carry micro particles from stormwater runoff to drainage. This will cause a build-up on the drainage bottom surface, which will overflow onto the drainage surface and cause disturbances to traffic flow [32]. Figure 8 shows high water velocity on the drainage that can cause sediment to pile up, as shown in Figure 9.

Figure 8. High velocity water flow, Nagoya Sub – District, Source : Real time observation

Figure 9. Sediment build after storm water receed, Nagoya Sub – District, Source : Real time observation

In cases of existing conditions, the result can cause damage to the road structure, such as cracks or potholes due to water accumulation and heavy traffic, as well as damage to private or public vehicles. which will reducing road funcitionality and disrupt traffic and human activities. Despite this, Batam city's drainage systems need to follow outside methods, such as those used in Finland, which include sediment traps on stormwater manhole covers, as shown in Figure 10. This will allow water to flow through the filter, trapping sediments and preventing clogging or sediment buildup in drainage channels [33]. Another sediment trap could be used from New Zealand, which lowers the depth by 0.75 cm every 7 meters long. This design can reduce high water velocity, which would allow sediments to sink through the trap and not be able to flow to the main drainage channels [34].Which can be seen on Figure 11.

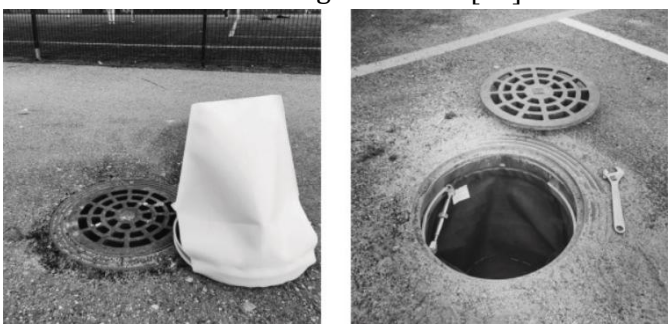

Figure 10. Sediment traps on manhole cover

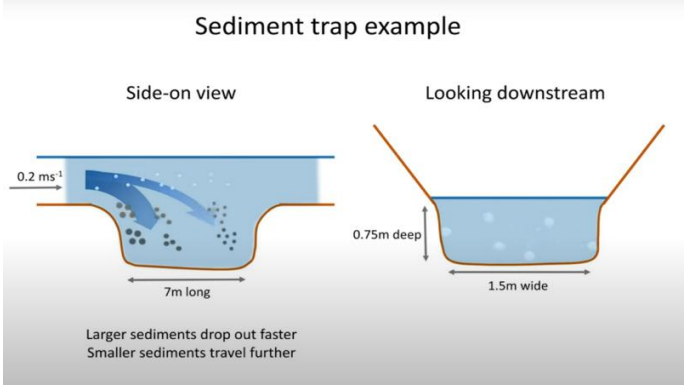

Figure 11. Sediment bottom base trap

5. Conclusion

To summarize everything that has been stated so far, Batam City, with its existing drainage conditions, is facing a massive problem with sedimentation buildup. This indicates that the drainage is consistently inadequate. The drainage cannot cope with heavy rainfall, which causes overflow and accumulates on the surface. These accumulations could disturb vehicle users, causing extreme traffic congestion, damage to upper and lower structures, and significantly reducing road functionality. So by using sediment trap on bottom base and manholes or drainage channels, it could increase water flow smoothly without disrupting water flow dynamics. This can also reduce floods and the impact on road structures, as well as increase road functionality.

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